Wireless Charging Stations for Electric Bikes

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Group 30

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1 Introduction

1.1 Objective

Electric bare becoming more popular especially for rideshare services in cities. Companies like Lime and Bird have racks of bikes in cities where users can unlock a bike, use it for their commute and then return it to another bike rack. An issue with this system is that currently, these companies have people manually pick up the bikes and charge them at night [5]. This is not ideal that all of the electric bikes in the fleet have to be changed manually and is an issue if the company wants to add even more bikes. They will then need to also hire even more contractors just to charge these bikes. This increases costs at a higher rate because it will not just be the cost of electricity but also manual labor.

Our proposed solution for this issue is to make the bike rack a charger for the electric bike. So that every bike will be charging any time it is placed in a rack. If these companies then used the modified bike racks for their electric bikes, then Lime, Bird, and other similar companies wouldn't need to worry about needing to manually have someone pick up all of the bikes and charge them. The companies could also increase the fleet size without worrying about how it will cost more in labor to get extra bikes charged. The only increased cost would be electricity but that is much cheaper than manual labor.

1.2 Background

Currently, these companies are hiring contractors to manually charge the scooters [2]. They have to spend extra money just to have the feet fully charged in the morning. Since the workers are contractors and it is not a full-time job so not every person will charge bikes nightly. Since it is not a 100% reliable group of people charging the bikes there could end up being some bikes that aren't charged by the morning. But if there was a bike rack that charged all the bikes docked into it simultaneously then this wouldn't be an issue. The only cost the company would have to worry about is the price of electricity to charge the bikes but that is still massively cheaper than paying contractors per bike per hour.

1.3 Visual Aid

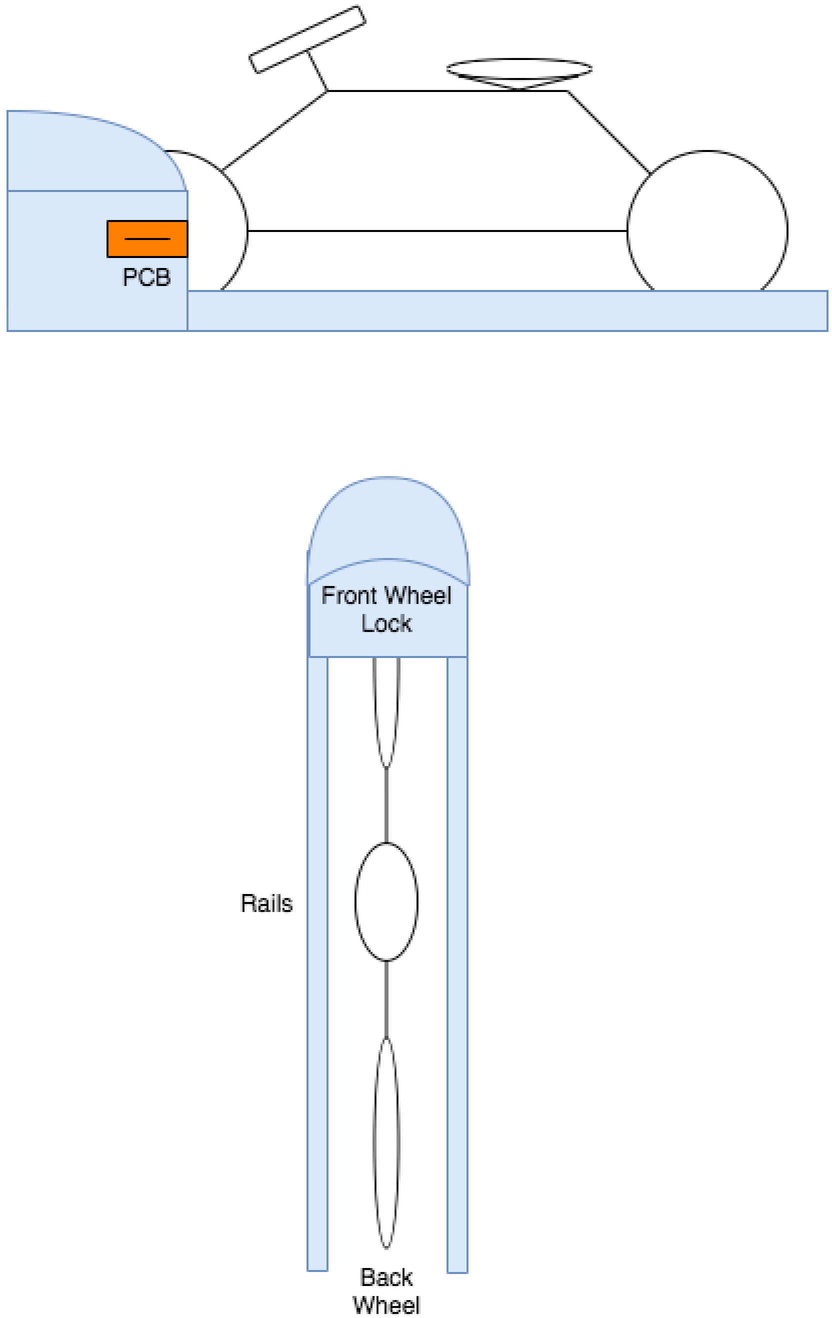

Figure 1: Side and Top View of general mechanical design

1.4 High-Level Requirements

- The wireless charging method will need to charge the battery from 10 V to 16 V at least within 12 hours

- The bike charging pad should detect when the battery is fully charged and signal the rack to cut power from the coils

- The bike rack should detect when a bike is inserted into the front tire hold and the tire rails and start the charging process.

- The bike pad and the rack pad should stop thermal runaway situations and the coils should never reach 85 degrees Celsius.

2. Design

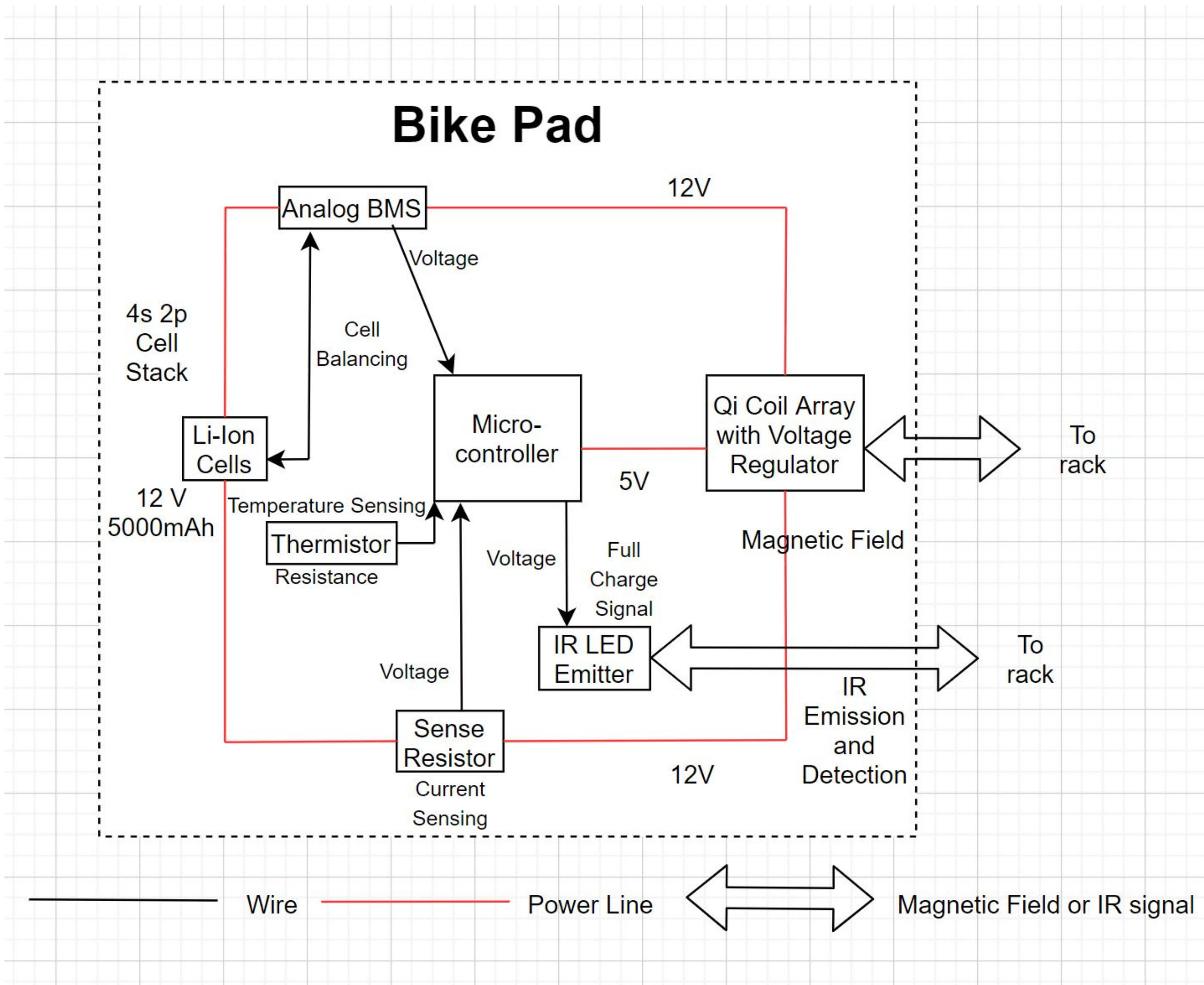

Figure 2: Logical Block Diagram for Bike Pad

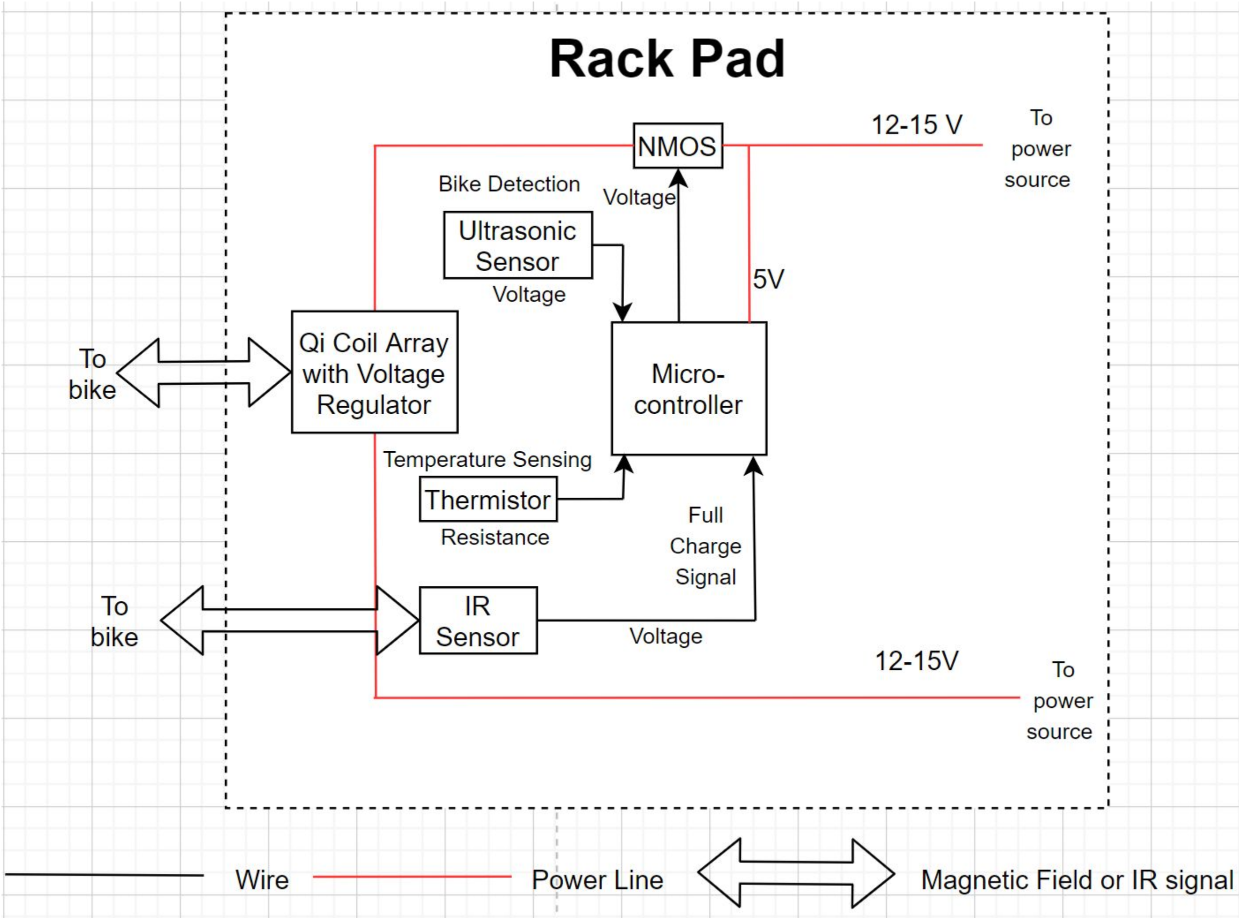

Figure 3: Logical Block Diagram for Rack Pad

The design is split between the bike and the bike rack. The bike pad will have the Li-Ion battery, receiving Qi coil array, a thermistor, IR emitter, a sense resistor, an Arduino UNO, and an analog BMS. The Qi coil array will be used to charge the battery and also power the Arduino which will turn on the IR LEDs as a signal to stop charging once the battery is full. The bike rack charger has the Qi coil transmitter array, Arduino UNO, ultrasonic sensors, a thermistor, 2 back to back NMOS, and an IR sensor. The bike rack will be used to charge the bike and will use the Arduino to turn off the power to the qi coils if the bike is not in the rack or if the bike is charged. This design satisfies the high-level requirements because the bike rack will be charging the bike and we chose coils that will be able to do overnight charging of the battery. The inclusion of the IR LEDs and IR sensor satisfies the requirement to turn off the charger. The ultrasonic sensors satisfy the requirement of only charging the bike when it is on the rack.

2.1 Physical Design

As indicated in figure 1, there will rails on the ground that will stand about 3 inches tall that will be spaced tire width apart. There is also an insert for the front tire that will encompass the front tile and will be covered to limit the amount of light. This is where the rack pad will be located and the bike pad will be mounted near the center axis of the front tire.The front tire inset will be 1 inch wider than the maximum width of the center axis of the tire.

2.2 Subsystem Requirements and Verification

2.2.1 Qi Coil Array on the Rack

The Qi coil array in the bike charger will use the incoming current to generate a magnetic field. This will be the transmitting coil.

Requirements	Verification
1. Transmit magnetic fields to the receiver with an inductance of 12μH 2. Input should be between 12 and 15 volts and voltage should be boosted for higher performance from the internal voltage regulator	1. Attach a DC ~15 V supply 2. Use a magnetometer in order to measure the magnetic field and compare it to the theoretical magnetic field shown in the datasheet

Table 1: RV Table of Transmitter Qi Coil

2.2.2 Qi Coil Array on the Bike

The Qi coil array in the electric bike will be a receiving Qi coil array. This array will generate a current from the magnetic field and use that to charge the electric bike.

Requirements	Verification
1. Receive a magnetic field with an inductance of 10μH 2. The output voltage from coils should be ~12V	1. After verification of the transmitter Qi coil, use the incoming magnetic field and use an ammeter to measure the output current. 2. Use a voltmeter to measure the voltage across the terminals of the coil.

Table 2: RV Table of Receiver Qi Coil

2.2.3 Analog BMS

The analog BMS should manage the battery pack and monitor battery voltage for overvoltage and under-voltage. The analog BMS should do cell balancing between the 4S cells. The BMS uses NMOS to limit access to the power path for the battery. We will tie a signal line to the source pin of the NMOS as a signal that the battery has hit a safety condition and we will block power to the coils.

Requirements	Verification
1. NMOS will block power when the total battery voltage is greater than 14.8 V +- .5 V 2. NMOS will allow charging when the undervoltage value of ~10.5 V is reached. 3. Cell balancing will be achieved to make sure cells have similar voltages. 4. Charging the Li-Ion pack should follow the recommend current charging curve (listed below as plot 1)	1. We can attach a sinking power supply as a “battery” on the B+ and B- side 2. We attach a 12+ power supply to the Pack+ and Pack - 3. Get the waveform over time of the current on the B+ and B- side. The current should be held constant until 50% capacity of the battery is reached and after current should be tapered down 4. Increase the voltage of the sinking supply source to 15+V and measure current at the source pins of the NMOS 5. Decrease the voltage of the sinking supply source to under 10 V and measure current at the source pins of the NMOS 6. Remove the sinking supply source and add 1 full 9 V battery and 3 empty 9V batteries in series. Allow the BMS to get current through. After 20 mins measure the voltage of each battery.

Table 3: RV Table of Analog BMS

2.2.4 Ultrasonic Sensors

The ultrasonic sensors will be placed on both sides of the bike rack and will be measuring the distance between them. If the bike is placed inside the rack then the distances calculated will be different and once the bike has been detected the bike rack will send power to the Qi coils to begin charging the bike.

Requirements	Verification
1. We want to make sure that the measurements taken by the sensor have an accurate distance measurement of with +- 3% in cm of the actual target distance. a. We will be checking the measurements in the range of 30 - 55 cm.	1. Power an Arduino Uno development board and use the 5V pin to power the ultrasonic sensor. 2. Place a flat surface in front of the ultrasonic. 3. Connect a 3V square wave to the trig pin. 4. Connect the data pin to a voltmeter and make sure the correct voltage is read out according to the datasheet.

Table 4: RV Table of Ultrasonic Sensors

2.2.5 IR Receiver

The IR receiver in the bike rack will detect when the bike sends an IR signal to the rack. If the signal is detected then the bike rack will cut off power to the Qi coils and stop the rack from charging the bike.

Requirements	Verification
1. Detect an array of IR LEDs with an intensity of 70 mW/sr +- 10mW/sr up to a max distance of 25 cm.	1. Connect the Vcc pin to a 5V power pin from an Arduino Uno Development board. 2. Connect the data pin to the voltmeter 3. Shine a 940 nm IR light and verify we have a voltage spike corresponding to when the light is shined.

Table 5: RV Table of IR Receiver

2.2.6 IR LEDs Emitter

The IR emitter in the bike will send a signal to the bike rack once the bike is done charging. This signal will be used to determine whether the bike needs to continue charging or not by the bike rack.

Requirements	Verification
1. The array of LEDs will emit light having a wavelength of 940nm and an intensity of 85 mW/sr.	1. Connect a 5V DC power source and use an IR detector or an IR detector app on a smartphone to detect the IR light.

Table 6: RV Table of IR LEDs

2.2.7 Microcontroller

The microcontroller in the bike rack will mainly be used to detect the ultrasonic signals and the IR signals. If the ultrasonic sensors have the distance change then there is a bike in the rack and the microcontroller should allow the power to get to the qi coils to charge the bike. If there is no bike in the rack the Qi coils should not be receiving any power. If there is an IR signal then the bike is done charging and the power to the Qi coils should also be cut. Also if the thermistor detects that the coils are getting dangerously hot then the power to the Qi coils should be cut too. This is powered by the power source.

The microcontroller in the bike will mainly be used to detect whether the Li-ion cells are done charging or not. If the Li-ion cells are done charging then the IR emitter should be emitting a signal. Also, the input to the Li-ion cells should be cut to prevent overcharging. Additionally, if the thermistor is detecting dangerous levels of overheating the Li-ion cells should be disconnected from everything including the motor to allow them to cool down.

Requirements	Verification
1. Be able to process analog measurements and use digital IO to drive outputs as can be seen in the software flowcharts.	1. Use an Arduino Development board to test the output voltage of the 3.3 V and 5V pins 2. Use a power supply to test the input range of the A0-A5 pins 3. Attach a voltmeter the D0-D13 pins to test the range the output voltage of the IO pins

Table 7: RV Table of Microcontroller

2.2.8 Thermistor

There is a thermistor on the bike rack. This is placed near the Qi coils and is used to detect if the coils are getting too hot. If the coils get too hot the resistance changes and the microcontroller uses this to know that it needs to cut power to the Qi coils to let them cool down. There is a thermistor in the electric bike. This is placed near the Qi coils and also near the Li-ion cells. If either the coils or the Li-ion cells overheats then the resistance will change. The microcontroller detects the change and cuts the connection between the Qi coils and battery to let them cool down.

Requirements	Verification
1. The thermistor changes resistance according to the curve given in the datasheet. 2. Nominal resistance at 25 C: 3.3 kOhmns 3. Resistance Tolerance: +3%/-3% (H), +5%/-5% (C)l	1. Connect the thermistor to a power source ~3V. 2. Connect an ohmmeter to the thermistor. 3. Use a heat source like a hair dryer to heat the thermistor and observe the change in resistance and verify it fits the model given by the datasheet.

Table 8: RV Table of Thermistor

2.2.9 NMOS

There are 2 back to back NMOS gates in the electric bike. We use 2 gates because by using 2 gates that will completely isolate the Li-Ion cells from the Qi coil. The gate closer to the battery has a higher capacitance. This is used to cut the power to the battery after the bike is fully charged. There are 2 back to back NMOS gates in the bike charger. We use 2 gates because by using 2 gates that will completely isolate the Qi coil from the power source. The gate closer to the Qi coils has a higher capacitance. This is used to cut the power to the Qi coils so that they are not active when the bike doesn't need to be charged.

Requirements	Verification
1. The NMOS will have a high Vds breakdown of 30-45V	1. Ground the gate and source of the NMOS 2. Attach a ammeter between the source pin and ground 3. Set the drain pin of the NMOS to 25+V 4. Observe low current through the ammeter.

Table 9: RV Table of NMOS

2.2.10 Li-Ion cells

The Li-ion cells in the electric bike are the battery and power the motor and other electrical components of the bike. They will be charged by using the receiving Qi coil on the bike pad. And they are also connected to the motor control circuit.

Requirements	Verification
1. Li-Ion pack will have a nominal voltage of ~14.5 V and a capacity of 5Ah	1. Use a voltmeter to test voltage per cell. 2. Connect all the 8 cells in a 4S 2P configuration 3. Use a voltmeter to test overall pack voltage.

Table 10: RV Table of Li-Ion cells

2.2.11 Sense Resistor

The sense resistor is used in the electric bike. This is used to detect the current flowing through the Li-Ion battery. If the current goes past a certain threshold then the resistor will detect it and the microcontroller will cut the connection between the Qi coil and the battery so that it can cool down.

Requirements	Verification
1. Resistor should have low ohm rating of 95-105 ohms	1. Use an ohmmeter to verify that the resistor is around 100 ohms +- 5%

Table 11: RV Table of Sense Resistor

2.3 Plots

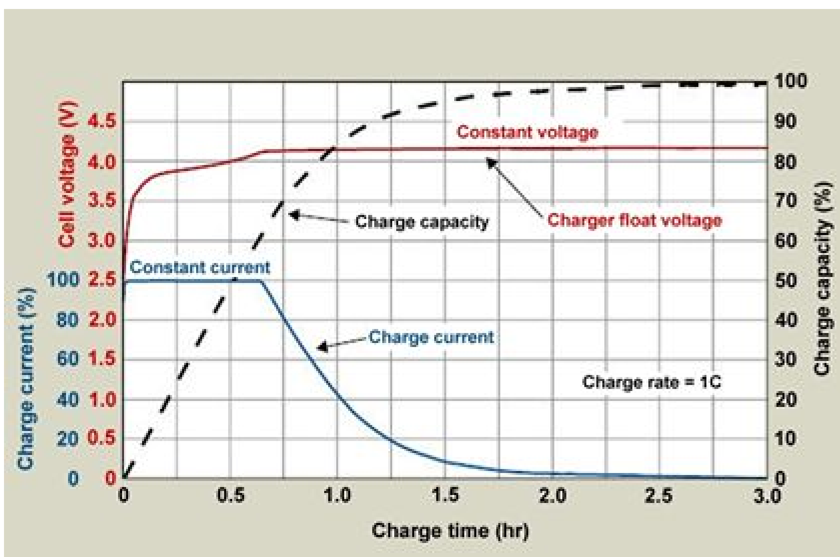

Figure 4: Charging Li-Ion Battery

Figure 4 shows the optimal charging curve of a Li-Ion battery pack. Here we can see that charge current is held constant and until charging capacity is ~66% and then charge current is tapered down. This can be achieved by lowering the gate voltage on the NMOS of the analog BMS to transition the NMOS from saturation to linear operating region and lowering the gate voltage as time goes on until the gate voltage will be lower than the threshold voltage and thus the NMOS will be off. Another important factor is that the charging voltage will be held constant when the charging current is being tapered down.

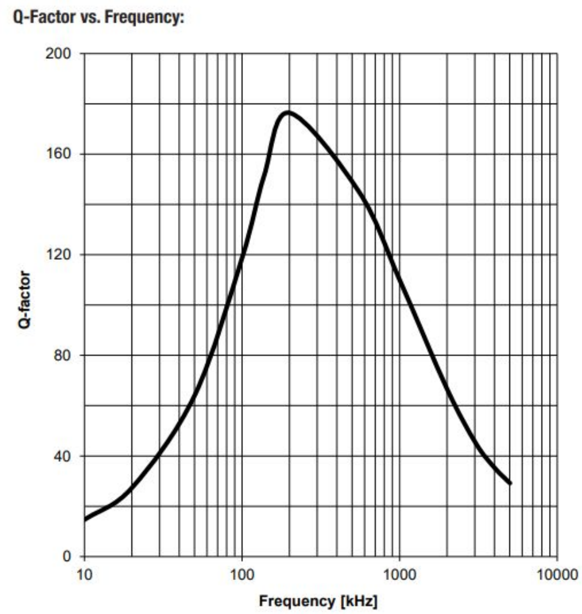

Figure 5: Q-Factor vs Frequency for Transmitter Qi Coil

Figure 5 shows the Q-Factor vs Frequency of the transmitter Qi Coil. The Q factor of an inductor circuit is used as an indication of its performance in a circuit. Q factor is determined by the ratio of its inductive reactance to its resistance at a given frequency. This information can be used to tune the frequency of the changing current in order to optimize charging.

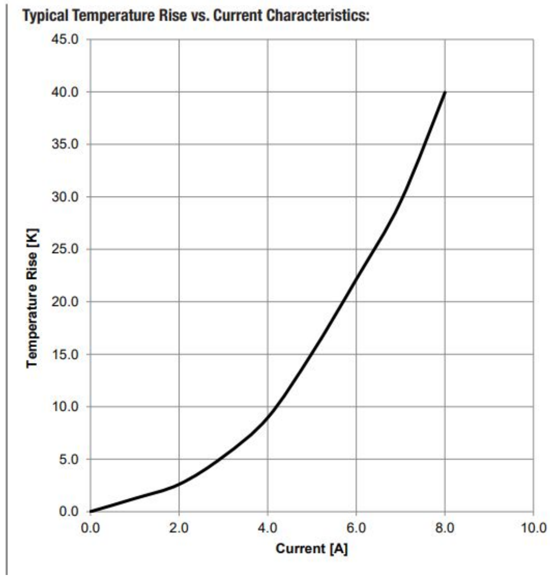

Figure 6: Temperature vs Current for Transmitter Qi Coil

Figure 6 shows the relationship between temperature and the current of the transmitter Qi Coil. We can use this information to tune for the correct temperature we will cut off power to the Qi coil in the case of overheating thus preventing an accident scenario.

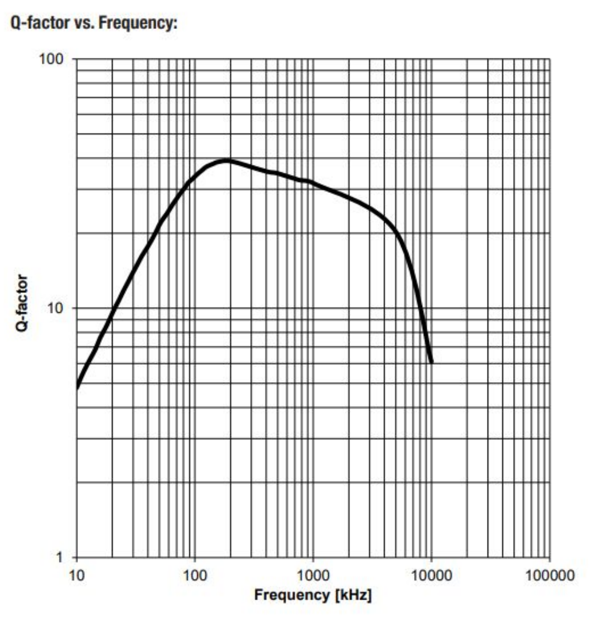

Figure 7: Q-Factor vs Frequency for Receiving Qi Coil

Figure 7 shows the Q-Factor vs Frequency of the receiver Qi Coil. The Q factor of an inductor circuit is used as an indication of its performance in a circuit. Q factor is determined by the ratio of its inductive reactance to its resistance at a given frequency. This information can be used to tune the frequency of the changing current in order to optimize charging.

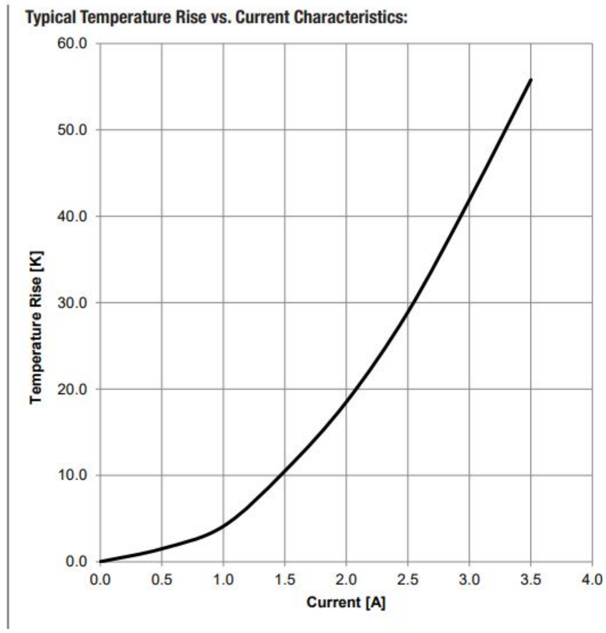

Figure 8: Temperature vs Current for Receiving Qi Coil

Figure 8 shows the relationship between temperature and the current of the receiver Qi Coil. We can use this information to tune for the correct temperature we will cut off power to the Qi Coil or lower the current to prevent overheating thus preventing an accident scenario

3. Schematic

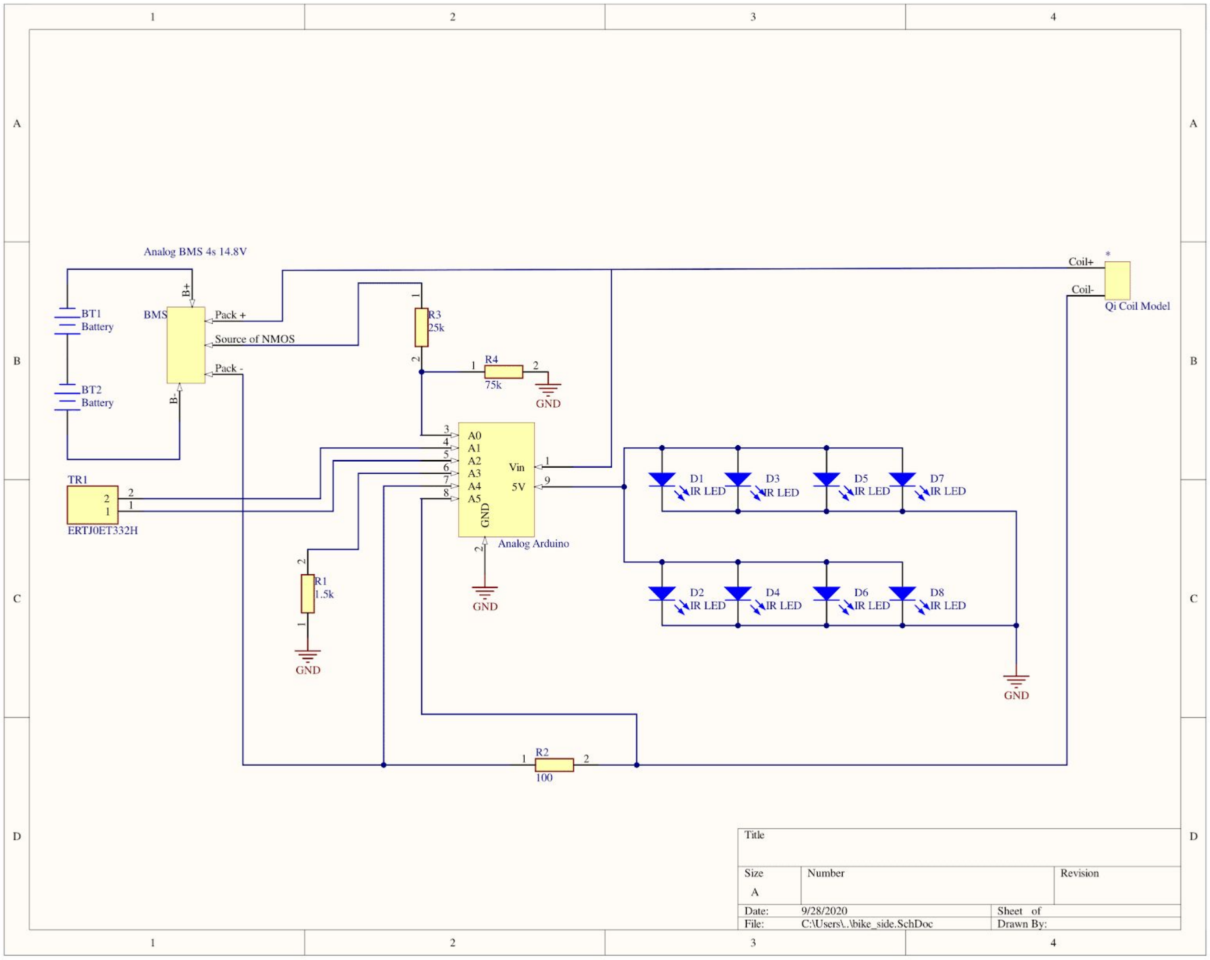

Figure 9: Bike Pad Schematic

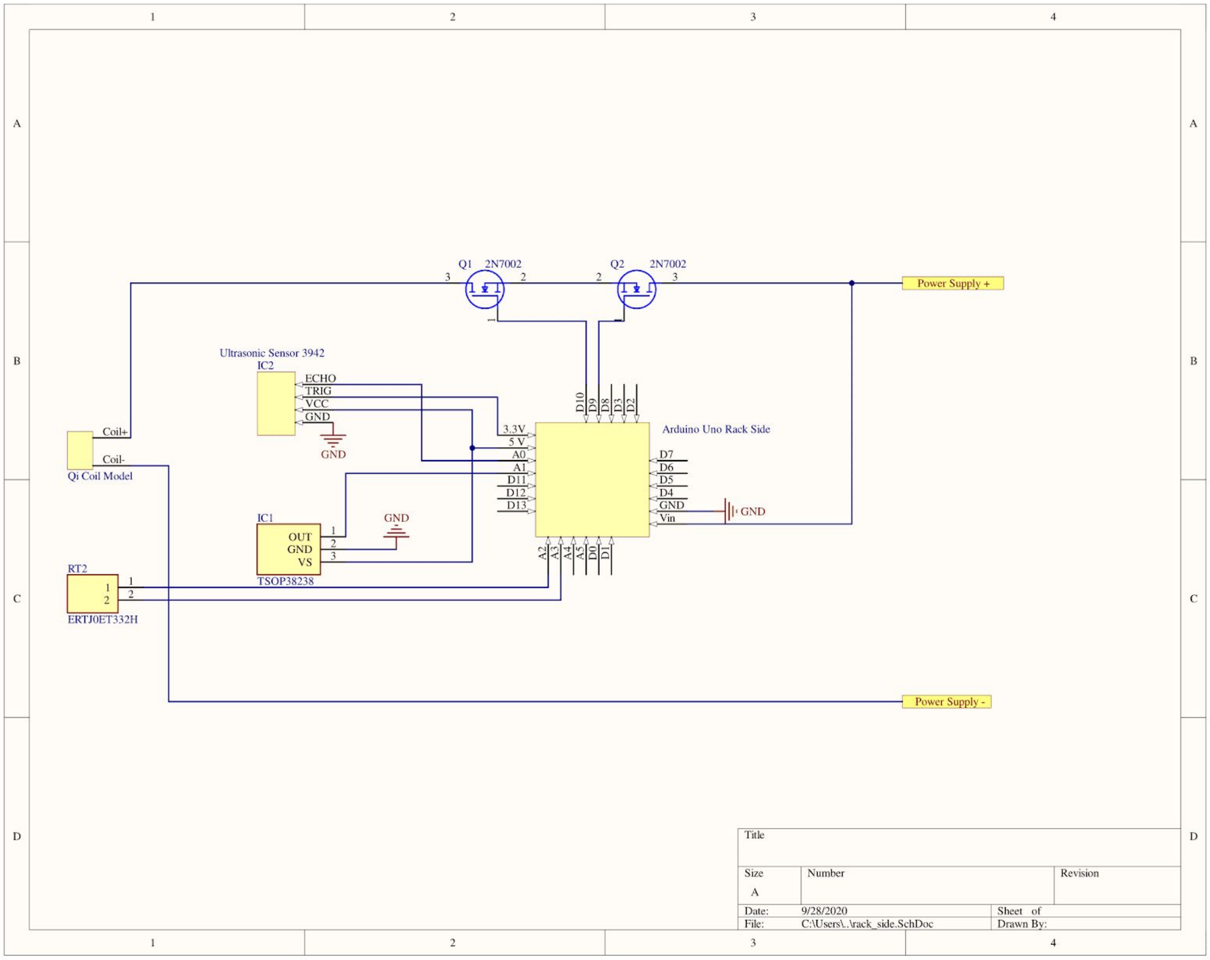

Figure 10: Rack Pad Schematic

4. Tolerance Analysis

The subsystem that is most critical is the transmitter and receiver pair of Qi coils. For the project to succeed we have to provide charging efficiency comparable to a wired charging. Our target efficiency is 75% of wired charging. The following equation describes the change of battery energy over time as the function of power [11].

$$dE_B(t) = P(t) \cdot dt = V_B(t) \cdot I_B(t)\, dt$$

Figure 11: Change of battery energy over time

Once we take the integral and discretize this equation we will get the following relationship.

$$E_B(t) = \int_{cycle} dE_B(t) = \int_{cycle} V_B(t) \cdot I_B(t)\, dt = \sum_n V_B(t_n) \cdot I_B(t_n)\, \Delta t$$

Figure 12: Integrating over energy equation

We can also model the change in the load energy as the change in the battery energy divided by the current from the battery

$$dE_S(t) = \frac{dE_B(t)}{\eta(I_B(t))} = \frac{V_B(t) \cdot I_B(t)}{\eta(I_B(t))}\, dt$$

Figure 13: Model of change in energy over battery current

We can combine these relationships to find charging efficiency per cycle which is listed as n is the equation below

$$\eta_{cycle} = \frac{E_B}{E_S} = \frac{\sum_n V_B(t_n) \cdot I_B(t_n) \cdot \Delta t}{\sum_n [V_B(t_n) \cdot I_B(t_n) / \eta\, (I_B(t_n))] \cdot \Delta t}$$

Figure 14: Charging efficiency per cycle

If we can get n_cycle to be 75% we can achieve the efficiency of the project. The typical energy drawn by a small E-Bike motor is ~150 W. Our customized battery pack for the model should be able to have the energy of ~120W. Which means for n_cycle is 120/150 or ~80% which is above our target. This means that over time the energy of the battery pack has to be 120 W and the receiver Qi Coil would provide that with 12 V with at least 1 A over 10hrs in the worst case.

5. Software

The software required for this project is the code that will go on the Arduino. The code will handle the input from all the sensors on the bike rack and decide whether to enable or disable the charger based on that. And on the bike pad, the Arduino will turn on the ir emitter once the battery is charged. The diagrams for the software on the bike rack arduino can be seen below.

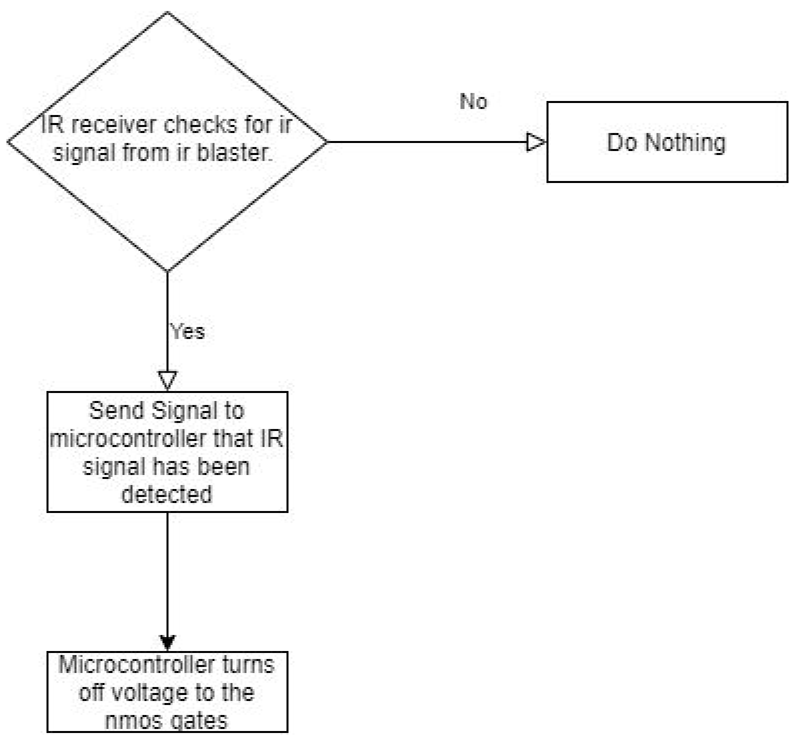

Figure 14: Software to check if Ir Signal is Detected.

Figure 14 shows what the microcontroller will do with the signal from the ir receiver. If there is an ir signal detected the microcontroller will turn off the voltage to the nmos gate and cut off the connection between the power supply and the transmitting Qi coil. So that is how the charger will be shut off once the bike is charged.

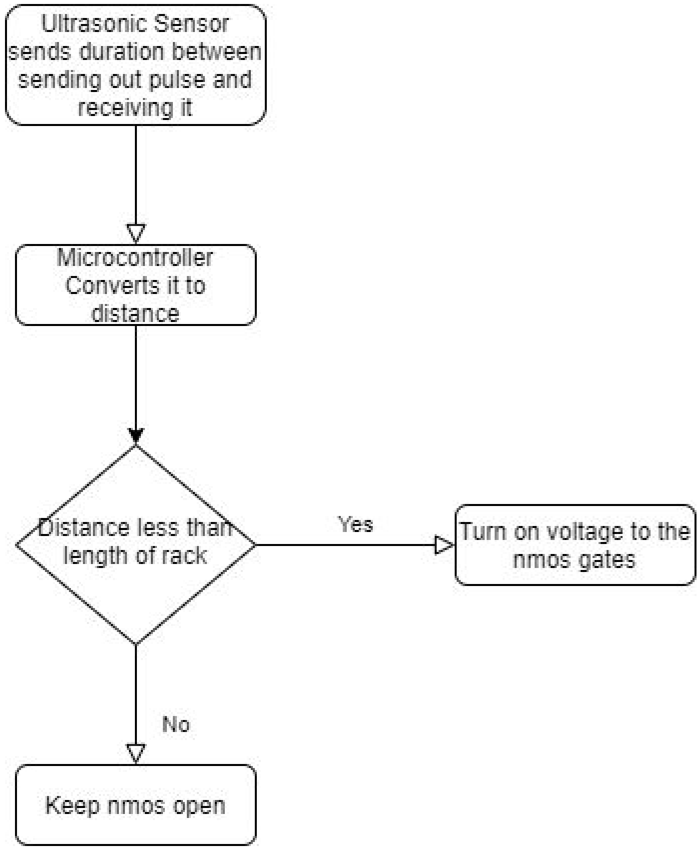

Figure 15: Software to check if a bike is present in the rack..

Figure 15 shows how the microcontroller will deal with the ultrasonic sensors. First the ultrasonic sensors are used to send out a pulse and get a measurement. Then this is converted into a distance and if the distance is less than the distance of the empty rack that means there is a bike in the rack. If there is a bike in the rack then the microcontroller will turn on the voltage to the nmos gate and turn on the connection between the Qi coil and the power supply. If the bike is not detected the nmos will be left open so that the charger will not be running without a bike.

6. Cost and Schedule

6.1 Cost Analysis

$40/hour * 10 hours/week * 14 weeks * 2.5 = $14000

$14000 * 3 teammates = $42000

Description	Manufacturer	Part #	Unit	Cost
Mosfet	Diodes Incorporated	2N7002	4	4 * $0.25 = $1.00
Transmitter Qi Coil	Würth Elektronik	760308104113	1	$15.29
Receiver Qi Coil	Würth Elektronik	760308103202	1	$6.05
Ultrasonic Sensor	Adafruit Industries LLC	3942	3	3 * $3.95 = 11.85
IR Sensor	Vishay Semiconductor	TSOP38238	2	2 * $1.12 = $2.24
ATMEGA328P-PU	Amtel	ATMEGA328P-PU	2	2 * $2.08 = $4.16
Analog BMS	Daier	E880	1	$9
Battery Cells	Samsung	INR18650-30Q	2	2 * $29 = $58
1.5 kOhms resistor	Panasonic	ERJ-6GEYJ152V	10	10 * $0.049 = $0.49
Thermistor	Panasonic	ERT-J0ET332H	10	10 * $0.088 = $0.88
IR LEDs	Adafruit Industries LLC	ADA388	25	25 pack for $12.18
Current Sense Resistor	Würth Elektronik	561020132009	1	$0.23
25 kOhms resistor	Vishay Dale	PNM0402E2502BST1	1	$0.98
75 kOhms resistor	Panasonic	ERA-2AEB753X	1	$0.39
16 MHZ Crystal	TXC Corporation	9B-16.000MAAJ-B	2	2 * $0.39 = $0.78
22 pf Capacitor	Vishay BC Components	K220J15C0GF5TL2	10	$1.52
100 microfarad Capacitor	Rubycon	35ZLH100MEFC6.3X11	3	3 * $0.3 = $0.90
Labor				$42000

Table 1 : Total cost

Total: $125.54 + $42000 = $42125.54
The total cost of our product including labour and the bike pad and the bike rack charger pad will be $42,125.54. The main cost other than the labour is the Li-Ion cells and if this was made in bulk by Lime or some other company that already has Li-Ion cells in bulk then it will be cheaper to manufacture these chargers. The rest of the parts will also be cheaper in bulk but for the prototype they are a bit more expensive.

6.2 Schedule

Week	Ron	Maneesh	Gong
7	Validate Analog BMS and finish PCB layout	Validate the microcontroller and figure out the best way to bootload them.	Validate IR LEDS, IR Sensors and Ultrasonic Sensors
8	Make Li-Ion battery and test charging with Qi Coils	Bootload the microcontrollers. Also start writing and testing the software to put on the chip.	Start writing software for the microcontrollers.
9	Test full design on breadboard	Test software on microcontroller on breadboard.	Validate all other parts not tests including bootloader hardware
10	Test PCB and makes necessary solder connections	Test the PCB and make sure all the sensors and software work on it.	Test PCB and makes necessary solder connections
11	Intergate PCBs with mechanical design	Integrate PCB and sensors with the bike rack.	Start on presentation for demo
12	Finish up project for demo	Finish up project for demo.	Finish up project for demo.
13	Final Report and Presentation	Final Report and Presentation.	Final Report and Presentation
14	Final Report and Presentation	Final Report and Presentation.	Final Report and Presentation
15	Final Report and Presentation	Final Report and Presentation.	Final Report and Presentation

Table 2 : Project Schedule

6.3 COVID-19 Contingency Plan

In the case that classes move to online instruction, we still plan on completing the project according to our original plan. We are confident in building the bike rack on our own. One problem that we would run into is the testing and verification of our coils, Li-Ion batteries, and battery management system. We were planning to use lab equipment to do the testing and verification of these key components.

Our contingency plan is to do the testing and verification on our own. We can use a regular wall outlet as our power source and turn the ac power into dc power using a buck regulator. This acts as the power source of our project. We can also use commercial multimeters in order to get voltage, current and ohm measurements and this should cover most of the measurements we need to make. We will also need testing equipment like multimeters, soldering irons and power supply but these are items we are purchasing in order to do the project remotely.

7. Discussion of Ethics and Safety

7.1 Ethics

In order to evaluate the ethics of our project we will be following the IEEE standard of ethics which generally state " to hold paramount the safety, health, and welfare of the public". One ethical problem that we could face is having people's credit card information being wiped out by our bike charger. If someone accidentally put their wallet or credit card in between the tire clamps and charging unit, the magnetic field generated could interfere with the magnetic strips at the back of credit cards. Although this is likely a very unusual occurrence, the charging station can still damage people's credit cards. A solution to this would be to create a physical barrier to prevent credit cards being inserted into the rack. With this it will be hard to align the magnetic field with a credit card without destruction to the bike rack.

Another ethical problem is that we will not have any false advertising of the product. We will clearly explain the purpose of the bike rack is to charge the bike overnight and it is not providing fast charging or anything like that. The chargers will also help the companies by doing some charging during the day when the bike is in the rack but this is not the main purpose of the bike rack charger. We will also make it clear that the charger can cause harm if tampered with or misused and any harm coming from misuse/tampering is not our responsibility.

7.2 Safety

One safety concern we have is with people tampering with the bike racks and possibly being electrocuted by tampering with the bike pad, rack pad or the Li-Ion cells [4]. Another concern we have is when the Qi coils in the ground pad and bike pad overheat or reach a temperature which can cause burns [13]. This can be especially dangerous to users if the coils have poor temperature regulation and the hazard increases if the heat from the coils creates a thermal runaway situation on the Li-Ion cells. This is a safety concern for people using bikes and people in close proximity to the bike chargers. To prevent this, we will have a thermistor connected to a microcontroller to detect dangerous levels of temperature. When situations with dangerous temperatures arise the microcontroller creates a signal on the bike side and the microcontroller on the rack side with cut power the coils.

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