Project E-Bike

Group 12

Group members

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1.0 Executive Summary

Very recently there are large pushes for people to begin switching from combustion engines to electric cars. Many state it's better for the environment in a time when the world is slowly heating. However, there are many people who don't have to money or the need for a large vehicle in order to get places or to move different items around.

Instead of using vehicles for transportation or to haul small items such as groceries instead we propose using electric bicycles (e-bike). These will not work for some Americans because we our infrastructure is designed around having automobiles. In other parts of the world, however, like for example in Europe the distance between buildings are not as far apart as here so a bicycle would make more sense there.

This report will detail the steps taken to design and plan the ability to change a bike to an electric version which will enable faster travel. Firstly, will be the outline of the background of the different technology that is planned to be used in the project. This includes problems that used to be present, problems that are happening now, and possible problems in the future.

Afterwards, we will state the goals we wish to accomplish with this project and along with those goals will be the objectives, requirements, and constraints that we will need to accomplish to achieve our goals. Then will be the design layout of the project which will include the hardware and the software. Finally, we will state the reasons as to why we decided to go with the items we did and not others along with problems we found that may need to be fixed in later versions.

2.0 Project Description

The goal of the project is to create an e-bike conversion kit that will allow usage through an app connected via Bluetooth. The e-bike will include a cruise control that will be activated on the app along with having battery level gauge sent to your phone. This will allow easy access to the e-bike's modes and status.

2.1 Project Motivation

People need to use automobiles to go nearly everywhere nowadays, needing to go to school, work, or the grocery store. Everyone uses cars because everything is far from each other and the use of a bike either takes too long or there is not enough space. An e-bike gives more freedom to the user. Compared to electric vehicles, an e-bike is less expensive, and a better alternative means of transportation in a city. The inexpensiveness of an e-bike compared to a vehicle allows more users compared to the cost of an automobile.

2.2 Goals

Goals for this project include, but are not limited to:

Fundamentals:

- Being able to use the bike without pedaling.
- Providing enough speed to maintain balance.
    - (Hopefully not fall off from going too slow)
    - The amount depends on the environment.
- Engineering Goals:
    - App
    - Throttle control for speed
    - Cruise control
    - Ensure a constant speed that the user decides.

Stretch/advanced goals that are not currently in the active scope, but can be worked on after main goals are met:

- Regenerative braking will help with the distance the electric bike will be able to go.
    - Energy generated from braking can be used to charge battery.
    - The amount depends on the environment.
    - There will need to be an analysis of the weight added to the energy given back.
- Building an application that is paired via Bluetooth to send and receive information to and from the bike.
    - Such information will include, but is not limited to:
        - Battery level
        - Time spent on the bike for a specific event.
        - Current speed
- Create a lighting system that would allow riders to always ride safely in the day and night.
- Providing an assist mode.
    - This mode will help you when pedaling.
        - For example, when going up a hill the force required to continue going up the hill increases.
        - When using assist mode, the motor will make up for the increase needed to go up the hill.

2.3 Requirement Specifications

These are the design specifications. We plan to follow these closely as we design and create our project. Though these specifications are subject to change at any point during the project, they will aid us in structuring the design and guide us in the right direction for success.

2.3.1 - Production Cost

- We are making efforts to keep the cost of all the components to under 1000 dollars.

2.3.2 – Weight

- The total weight of the project is going to be 35 lbs. or 15.88 kg.
- Most of the weight will be given from the bike frame that approximately 20 pounds.

2.3.2.1 – Motor

- A weight estimate for an electric bike motor is about 4 kg or 8.8 lbs.

2.3.2.2 – Power

- Batteries that are about 500-watt hours can weigh up to 6 – 8 lbs. or 2.7 - 3.6 kg.

2.3.3 – Dimensions

2.3.3.1 – Tires

- 26 in x 1.95 in – diameter x width (DW)

2.3.3.2 – Motor

- 10 in x 2 in x 2 in – length x width x height (LWH)

2.3.3.3 – Battery

- 400 x 150 x 100 mm LWH

2.3.4 – Speed

- At least walking speed (2-4 miles per hour)
- At most: electric bike Class 2 standards of 20 miles per hour.

2.3.5 - Power

- 250-350 Watts
- Frame mounted
- Rechargeable Lithium Li-ion

2.3.6 - Motor

- A brushless motor with sensors will be used for efficient operation.
- We are trying to have the motor carry someone of about 250 lbs.

2.3.7 - Microcontroller

- Different sensor input detections (throttle, battery, fuel)
- Output comparison component
- Control of the brushless motor

2.3.8 - Speed Controller

- Since in our design, we are using a brushless motor with sensors, we have the option of using either a sensor or sensor less speed controller.
- The use of a PID controller will be what we use for the speed controller.

2.4 Block Diagrams

2.4.1 High Level Overview

This diagram covers the main pieces of the bike as individual components. A central control module will use electrical power that can also drive the bike motor. Peripheral inputs, such as throttle control, brake levers, and mode selector also feeds signals into the controller to determine the bike's behavior. The controller also outputs data and information to an app that can be used as a display or log that data.

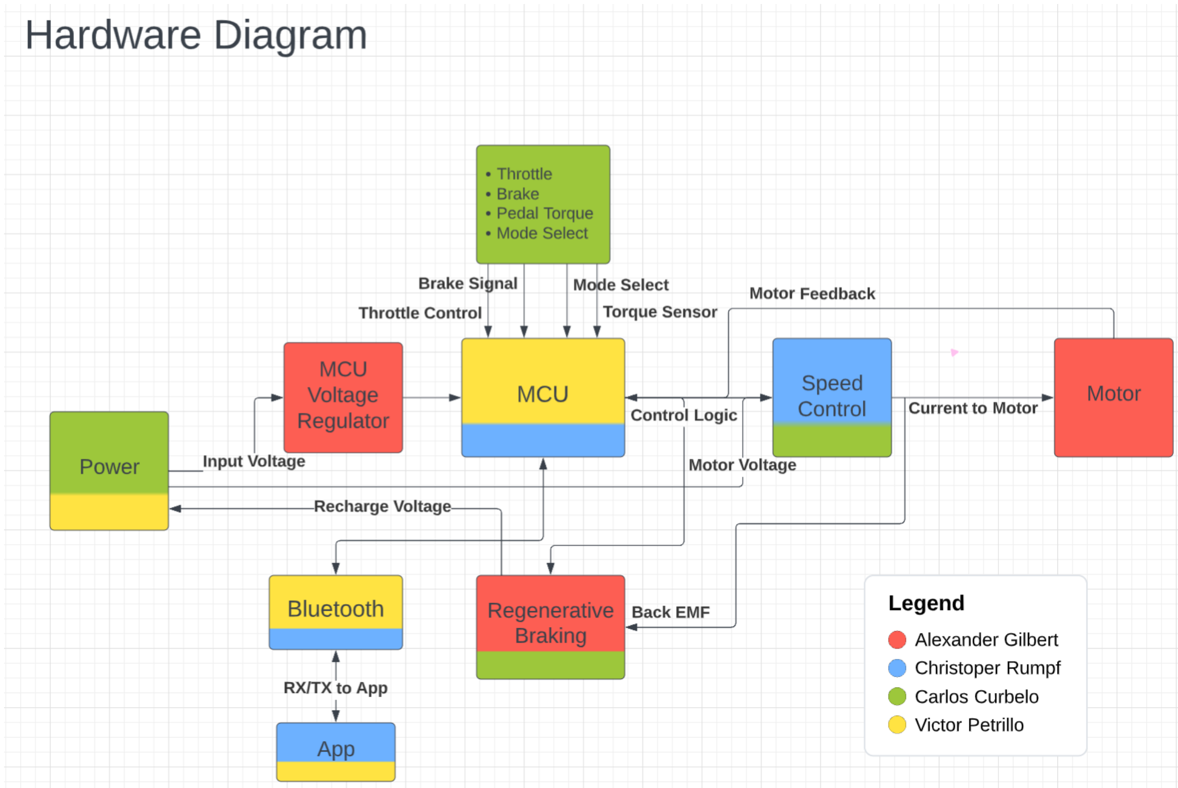

Figure 1: Hardware Diagram

2.4.2 Controller Diagram

Within the control board the main logic of the bike will be a microcontroller (MCU) that will take in all the signals and data. The MCU will be powered by the bike's main input power using a voltage regulating circuit. Motor control is done via a speed control circuit. The MCU will use feedback from the motor to regulate speed based on the bike's signals and feedback. Also, a regenerative braking circuit will be able to take the counter-electromotive force (back EMF) from the motor to recharge the battery. Any data that is logged, displayed, or input signals from the app will communicate to the MCU via a Bluetooth module.

2.4.3 Logical State and Flow

This state diagram shows the logical flow of the bike's MCU. When initially powered on the bike would be in an idle position where the bike can then be used as a bike with no electrical input or change into a powered mode using the motor. Using the throttle would put the bike in a driven state where the bike is powered by the motor regardless of the rider pedaling. An assist state is also available where the motor is used only to help the rider pedal such as making going up a hill require less work. When the brake lever is pulled, the controller will attempt to recharge the battery using back EMF from the motor.

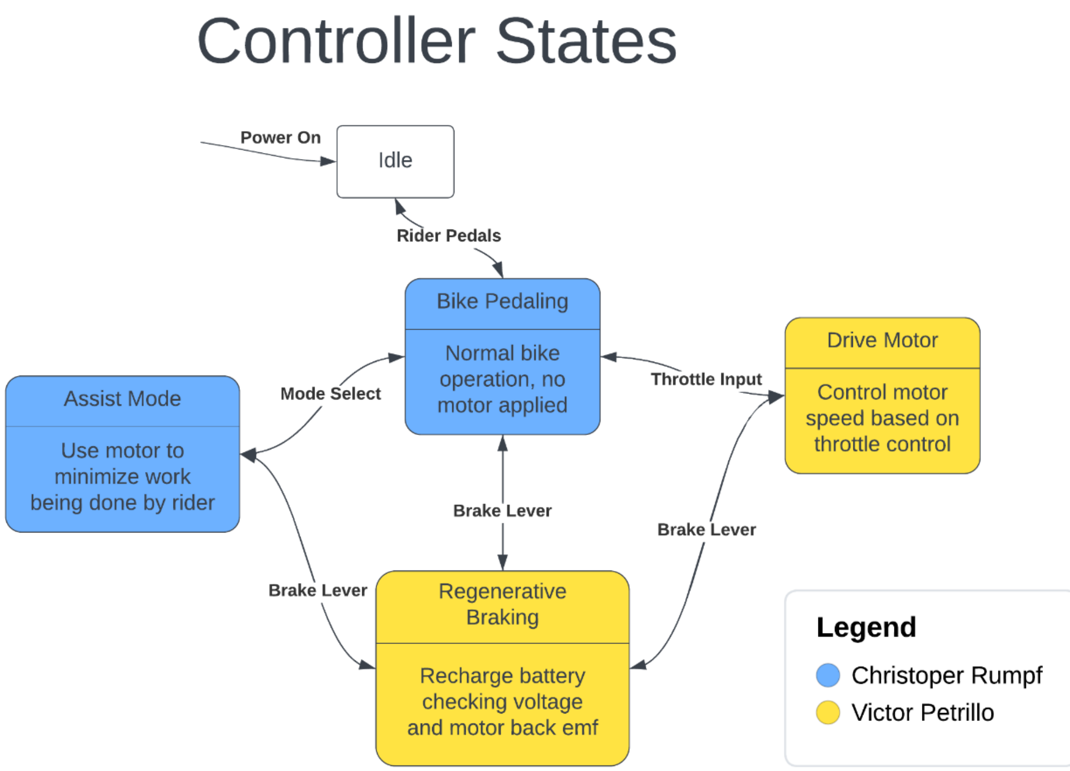

Figure 2: Control states

2.5 Project Budget

Item	Estimated Price
Motor (1 unit)	$200
PCB (3 – 5 units)	$20
Batteries (1 unit)	$250
Sensors	$50
Circuit components	$100
Forecasted Total	$620

Table 1: Budget Breakdown

2.6 Project Milestones

These are the milestones set for our group as directed for both Senior Design 1 and Senior Design 2. Completion of each milestone is subject to change as each due date passes. Any updated dates will be changed in the updated version of the document.

2.6.1 Tentative Senior Design 1 Milestones

Due Date	Milestone
Week 1 (1/29/23-2/4/23)	Divide and Conquer
Week 2 (2/5/23-2/11/23)	Divide and Conquer Meeting
	Editing and making changes of the Divide and Conquer
Week 3 (2/12/23-2/18/23)	Divide and Conquer website update
Week 4 (2/19/23-2/25/23)	15/60 Pages
Week 5 (2/26/23-3/4/23)	30/60 Pages
Week 6 (3/5/23-3/11/23)	45/60 Pages
Week 7 (3/12/23-3/18/23)	Spring Break & 60/60 Pages
Week 8 (3/19/23-3/25/23)	60 Page Draft
Week 9 (3/26/23-4/1/23)	60 Page Feedback | 75/120 Pages
Week 10 (4/2/23-4/8/23)	PCB Designing | 90/120 Pages
Week 11 (4/9/23-4/15/23)	60 Page website update | 105/120 Pages
Week 12 (4/16/23-3/22/23)	Review, Editing, Polish BOM | 120/120
Week 13 (4/23/23-4/29/23)	120 Page Final Report
Week 14 (4/30/23-5/6/23)	In-between weeks
Week 15 (5/7/23-5/13/23)	In-between weeks

Table 2: SD1 Milestones

2.6.2 Tentative Senior Design 2 Milestones

Dates	Milestone
Week 1 (5/14/23-5/20/23)	Build
Week 2 (5/21/23-5/27/23)	Build
Week 3 (5/28/23-6/3/23)	Build
Week 4 (6/4/23-6/10/23)	Building / Testing
Week 5 (6/11/23-6/17/23)	Testing
Week 6 (6/18/23-6/24/23)	Middle Term Demo
Week 7 (6/25/23-7/1/23)	Make Changes
Week 8 (7/2/23-7/8/23)	Conference Paper

Week 9 (7/9/23-7/15/23)	Build & Edit Paper
Week 10 (7/16/23-7/22/23)	Test & Edit Paper
Week 11 (7/23/23-7/29/23)	Final Presentation and Demo
Week 12 (7/30/23-8/5/23)	Senior Design Web Exit Interview

Table 3: SD2 Milestones

2.7 House of Quality

The most important engineering criteria and the critical marketing requirements will be systematically laid out in the house of quality that we created. This product needs to meet several important criteria in order to be marketable. We identified six areas where we would like to meet clients after carefully examining the market of the product. Regarding how we will meet the marketing needs, engineering requirements are the key focus. To pique consumer attention, we must address six crucial components of engineering needs.

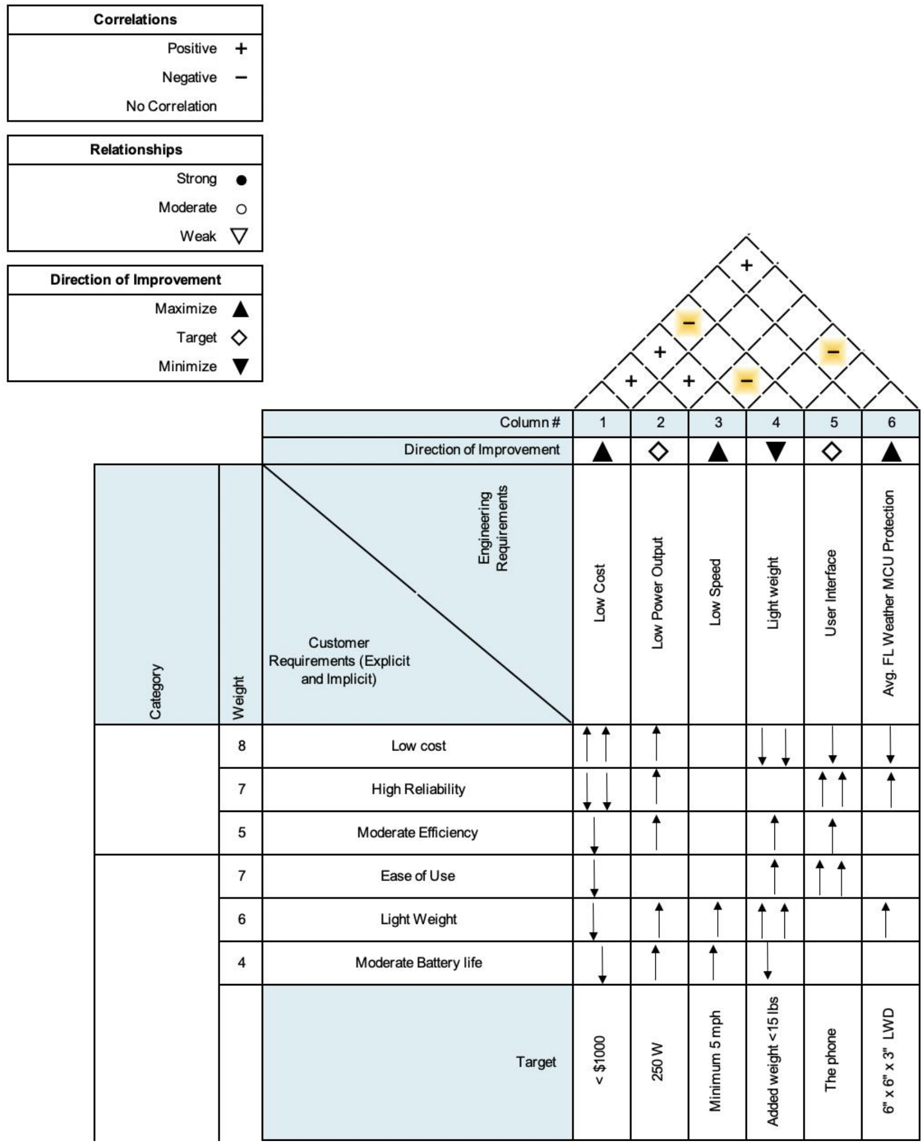

Figure 3: House of Quality

Keeping the development cost low for the group typically has a negative correlation with certain customer requirements. Having a lower power output correlates positively with most of the customer requirements because having a lower power output can result in increased longevity and efficiency, a lighter weight, and a lower cost. The speed of the bike doesn't correlate much with the customer requirements at all, other than how heavy the bike is and how much battery life is left.

3.0 Research related to project and part selection

In the divide and conqueror document the group did a preliminary block diagram for what we believe will be needed for the entirety of the project. An updated and complete version of a hardware block diagram will be added to this document as more information is learned and understood throughout the length of this project. The subsections below will contain all technology that was found and is relatable to the completion of this project. There will also be product investigation and with that a pro and con chart for the different product available that may be used in the future.

3.1 Batteries

There are primary and secondary batteries. The former is a single use while the latter is the more common type we see where the battery is rechargeable. The reason for the differences is that the electrode materials are made in a way that is not reversable while the electrodes in a secondary battery are reversed when applying an electric current. In the case of this project we will need to use a secondary type so the battery on the e-bike will be able to be reused.

Batteries transfer charge by using a process called oxidation and reduction. This was first discovered by an Italian named Alessandro Volta using copper and zinc separated by a saltwater solution. Oxidation is when a substance loses electrons (the zinc from the previous example) and transfers over to the substance gaining electrons which is called reduction (the copper). This process is one time use for primary batteries where the oxidation and reduction process is not reversable. In secondary batteries, however, it is reversable but only for a certain number of charge cycles. This is accomplished by transferring the electrons back to the metal so the oxidation process can occur another time. Every time this process occurs there may be irregularities in the metal which keep the metal from oxidizing correctly. This may reduce the max charge or even kill the battery outright and no longer be able to hold a charge. An anion is a negatively charged ion.

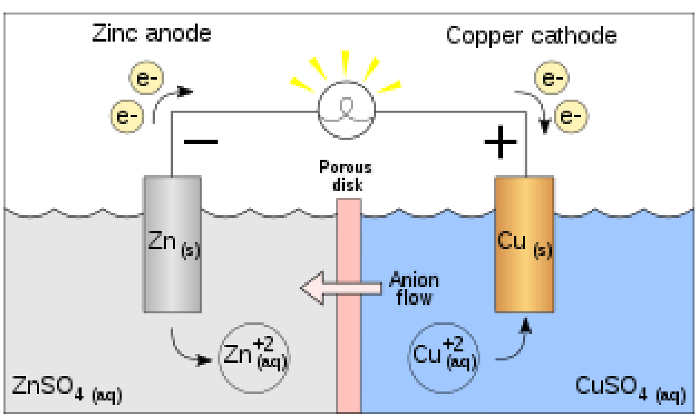

Figure 4: Galvanic cell flows

Batteries are affected by a few different characteristics. One is temperature. There are a few other characteristics such as the material used for a battery. This is primarily a concern for lithium-ion batteries which have a few different chemical makeups as opposed to the other secondary batteries that will be spoken of in 3.1.1 Secondary battery types – chemistry.

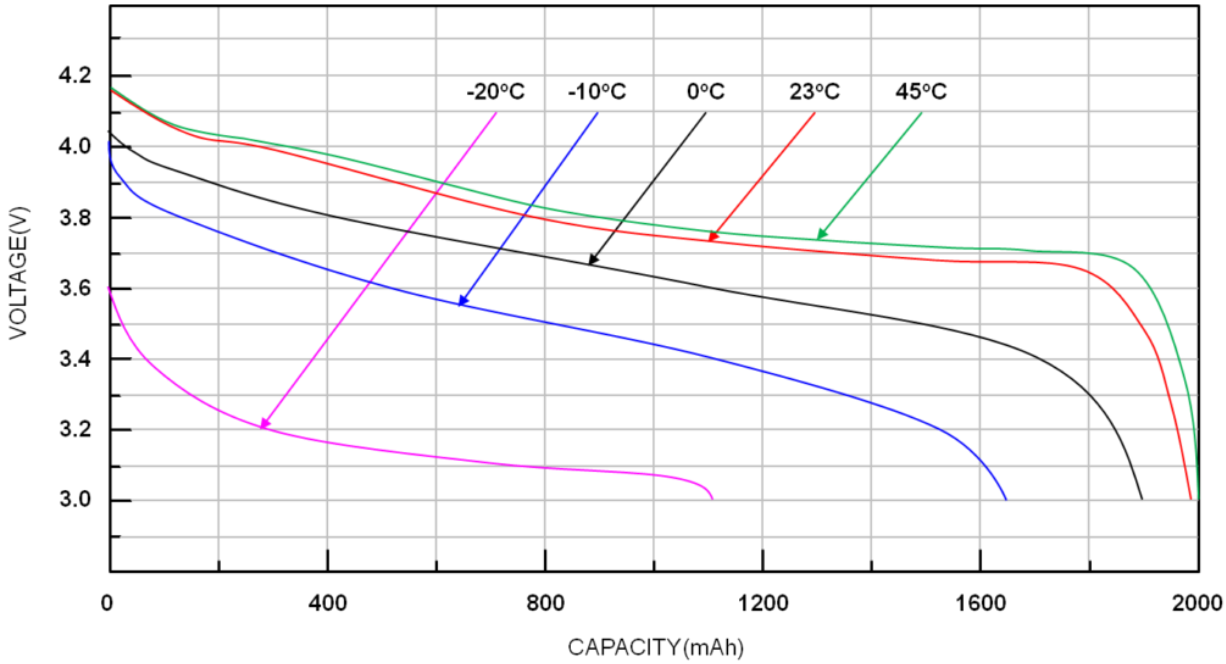

Figure 5: Voltage output at temperature variances

As can be seen above the voltage output of a battery decreases as temperature decreases. This means there is a nominal temperature for a battery to operate at, however, seeing as we are in Florida and the specifications for the project call for normal Florida weather there is no need to consider any large changes in output voltage.

Size has the main effect of changing the capacity of a battery (measured in amp hours Ah). This is a measure of how long a battery can last for one hour when pulling at that rate. An example of this happening can be seen in the figure under 3.1.1.2 Nickel-Metal Hydride batteries.

3.1.1 Secondary Battery Types - Chemistry

A basic visual for a secondary battery can be seen in the previous figure above in section 3.1 Batteries. There are many different chemistries for secondary batteries, however, there are specific chemistry types that are more well known than others. There are three main battery chemistries that are used today, one being lithium-ion, these are found in portable devices such as phones, and laptops. The second is a lead-acid battery, these are found in combustion engine vehicles, more recently, however, in electric vehicles the battery chemistry is lithium-ion. The third type of battery is Nickel-Metal Hydride (NiMH), which is found in rechargeable batteries from companies such as Energizer.

3.1.1.1 Lithium-Ion Batteries

Having a battery being Lithium-Ion is very broad because the electrodes have a few different options in regard to technology with different benefits and main applications. The anode is fairly consistent using some form of carbon. The cathodes are made with a metal oxide that always includes lithium. The most popular chemistries contain cobalt because of the stability of the element when reducing. However, cobalt is an expensive element along with nickel (which can be seen in other chemistries) so other alternatives are being looked at actively as a replacement. For example, a cathode of lithium iron phosphate (LFP; $LiCoO_2$) was discovered by Arumugam Manthiram and John B Goodenough and could be used as a cathode.

These batteries are considered to be the best secondary battery available because of a few factors. There are three main reasons to this. The first is the higher specific energy (other than LFP) of the battery being around 460 kJ/kg while the next most common would be the NiMH battery being at 360 kJ/kg. The Li-ion battery also has low rate of self-discharge from 0.35% to 2.5% depending on state of charge with an output voltage of approximately 3.6 volts. There are safety concerns for this battery that will be further explored in section 4.1.

3.1.1.2 Nickel-Metal Hydride Batteries

This chemistry is most often found in single celled rechargeable batteries used in video game controllers or places where a AA and are used as a replacement for alkaline batteries because alkaline batteries are nominal at 1.6 volts while NiMH operate nominally at 1.2 volts. The discharge rate is dependent on if the NiMH battery is a low self-discharge version at a cost of approximately 25% capacity. The discharge is 13.9% to 70.6% while the slow discharge rate is 0.08% to 2.9% which is comparable to Li-ion but at a lower energy density. Below is a discharge curve for an Energizer™ NH15-2300 rechargeable battery.

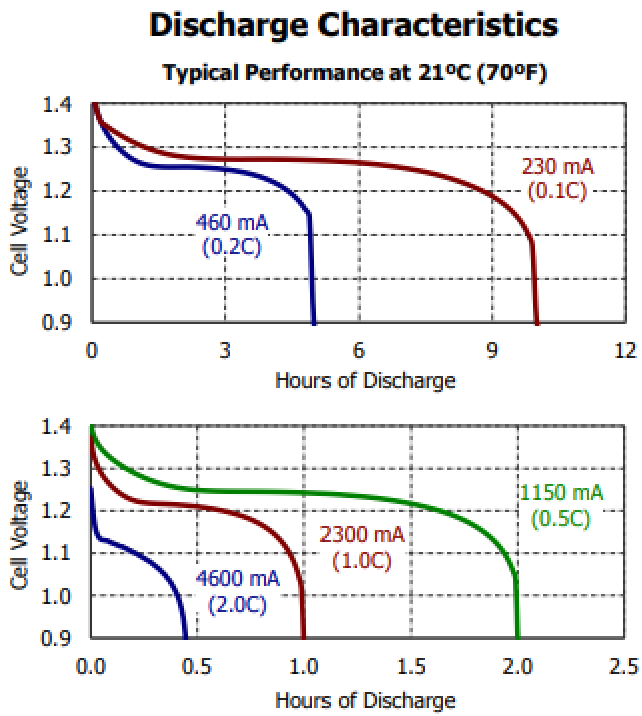

Figure 6: NiMH discharge characteristics

As can be seen in the above figure, cell voltage drops dramatically in the first 10 minutes of discharge but then depending on rate of discharge can be fairly consistent until a point in time when the battery no longer is capable of oxidizing and then the cell voltage immediately drops to 0.9 volts.

3.1.1.3 Lead-Acid Batteries

Normally used in vehicle operations because of the high surge current needed for start up a motor. However, these have a high discharge rate and few battery discharge cycles comparatively to lithium ion and NiMH. They are also very cheap comparatively so they can be used on other applications as well.

The chemistry consists of having a lead plate on both sides with a sulfuric acid solution in-between. The acid solution changes depending on if the battery is charged or discharges fully. Below is the figure for a fully discharged plate.

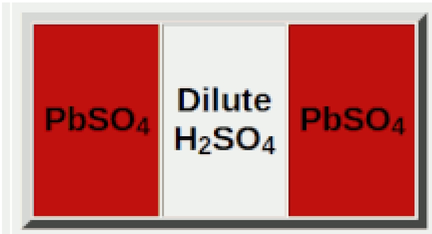

Figure 7: Fully discharges lead-acid battery

As seen in the figure above the two plates are the same being lead sulfate and the electrolyte becomes primarily water because the electrolyte becomes dilutes while discharging. Now will be the fully charged state of a lead-acid battery.

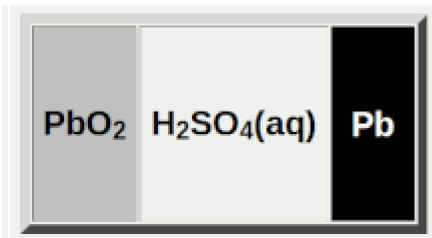

Figure 8: Fully charged lead-acid battery

In this case the negative plate is the lead while the positive is the lead dioxide and these plates are separated by a concentrated sulfuric acid.

3.2 Microcontroller (MCU)

A microcontroller (MCU) is a small computer that is built into an integrated circuit (IC). MCUs are used in many applications from appliances, robotics, vehicles, and more. An MCU will contain a central processing unit (CPU), random-access memory (RAM), read-only memory (ROM), and inputs and outputs (I/O) all on a single IC. Not to be confused with a microprocessor, which is a single IC that contains a CPU with none of the peripherals a MCU will contain: RAM, ROM, or I/O. MCUs can be designed for large applications with high CPU word sizes, 64-bit or 32-bit, and high clock speeds, small 4-bit or 8-bit sizes, and low clock speeds; or any combination in-between. They also have many different built in serial interfaces such as: recommended standard 232 (RS-232), inter-integrated circuit (I2C), serial peripheral interface (SPI), and controller area network (CAN). These serial interfaces can allow a MCU to communicate with other MCUs or sensors that support those protocols. Along with serial interfaces there are many peripherals that can be added: analog-to-digital converters (ADC), digital-to-analog converters (DAC), timers, pulse-width modulation (PWM) generators, and digital signal processing (DSP). Taking all these MCU design options into consideration the e-bike will use a single MCU with enough I/O and peripherals to do the necessary control and communication for the project.

3.2.1 Microcontroller Investigation

These next sections will cover an investigation of different manufacturers of MCUs and their products. Also, the MCU programming environments for development and debugging will be explored. The MCUs in consideration are not meant to be a complete market comparison but just a small subset of what is known, available, and easy to use.

3.2.1.1 Texas Instruments - Mixed Signal Processing (MSP) 430

Texas Instruments (TI) makes multiple models of MCUs but the one focused on here is the MSP430. The MSP430 is a 16-bit MCU that focuses on low power usage. The top speed is 25 MHz and has multiple peripherals such as PWM modules, I2C, SPI, and ADCs. Programming the MSP430 is done in the C/C++ or assembly language using TI's Code Composer Studio (CCS).

3.2.1.2 Microchip - Peripheral Interface Controller (PIC)

Microchip makes 8-bit, 16-bit, 32-bit, and dsPIC MCUs. Some of the higher end MCUs can reach speeds of 120 MHz or have 49 to 78 I/O pins. Certain models have built-in peripherals such as integrated Motor Control PWM and a Motor Encoder Interface which would help directly with the motor control portion of the project. PIC microcontrollers can be programmed using Microchip's PICkit which is a hardware serial tool for programming and debugging. Microchip also provides an integrated development environment (IDE) called MPLAB X as a tool for writing code in C.

3.2.1.3 Atmel – AVR

Atmel AVR is a family of microcontrollers designed and manufactured by Atmel Corporation, now owned by Microchip. The AVR microcontrollers are usually 8-bit. AVR microcontrollers are typically programmed using C and Atmel Studio (IDE). The AVR microcontroller is also the microcontroller of choice for the Arduino platform. Arduino is both the hardware and software meant to make building and programming microcontrollers easily accessible. Programming in Arduino is done using the Arduino Programming Language which is like C and C++.

3.2.1.4 Arm – Cortex-M

The company Arm designs and licenses a family of microcontrollers they also call ARM. The acronym used to stand for Advanced RISC Machine, with RISC being reduced instruction set computer. Arm does not manufacture any of their designs and instead licenses the architecture to other companies to build and add any peripherals. The main groups of Arm microcontrollers are Cortex M, R, and A. The groups have different applications with Cortex-A being application processes and would be used for operating systems like on Android or IOS phones and more. Cortex-R are for real-time applications and high performance, most are used in low level systems like hard drive controllers and airbags in vehicles. Finally, Cortex-M processors are more general purpose but still can be high performance and low power.

The focus for this project will be on the Cortex-M series. Because of the nature of the way Arm microcontrollers are manufactured it can be difficult to narrow down one way to program and use. There is one way to program Arm microcontrollers using Joint Test Action Group (JTAG) standard. JTAG is an industry standard for programming and connector layout. Also, Arm can be used with Arduino, Java, C, and many other languages.

3.3 Spatial Sensing

As an added safety feature the bike will be equipped with a sensor to determine its position and orientation in space. This can be done in a multitude of ways from vision implementations to proximity detection. The goal will be to have an added sensor that could detect impacts, orientation and potentially road gradients, and other operational data.

3.3.1 Accelerometer

An accelerometer is a sensor that measures an object's acceleration. The acceleration is the rate of change of velocity, and an object's velocity is the direction of its speed. Acceleration is measured in m/s^2 the most well-known value is Earth's gravity known as $g \approx 9.81\ m/s^2$. Accelerometers can be made in different ways from using a small, microscopic mass that moves inside the sensor called a micro-electromechanical system (MEMS). Another way is variable capacitive (VC) where a mass is between two plates and the change in capacitance is related to its acceleration. Also, piezoelectric which uses a piece of piezoelectric material to convert motion into an electrical signal. Depending on configuration, sensors can be setup for 1, 2, or 3 axes in space. Because of advances in manufacturing and parts becoming smaller, and more space effective, 3 axes sensors are common.

3.3.2 Gyroscope

A gyroscope measures an object's angular velocity, which is its rotation about an axis. Angular velocity is measured in *rad/s* or *degrees/s*. Like accelerometers, gyroscopes can also be MEMS or piezoelectric. The 3 axes in relation to an object's center of gravity have a name: pitch, roll, and yaw. Although these names are usually associated with aircraft the same names and applications can be applied to the bike.

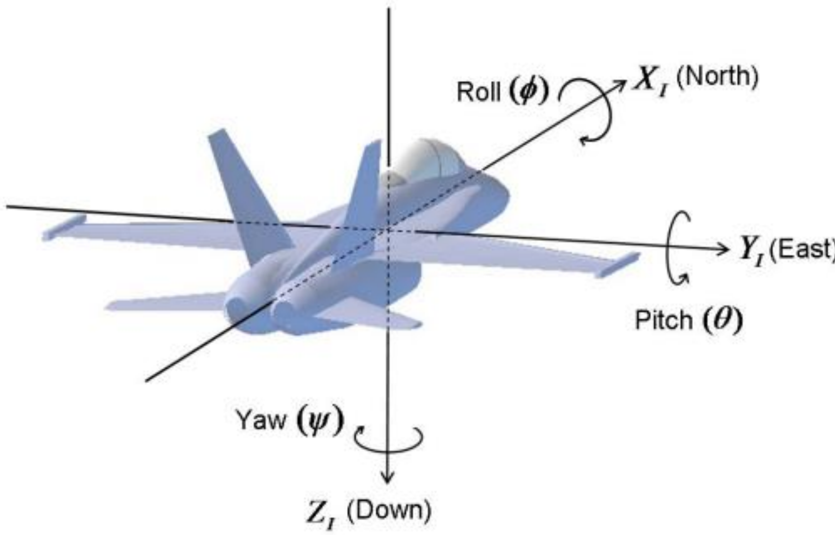

Figure 9: Pitch, Roll, and Yaw example (Copyright pending)

3.3.3 Magnetometer

A magnetometer senses magnetic fields; a compass is a common application. Magnetic field strength is measured in tesla (*T*). A smaller unit gauss (*G*) is 10^{-4} *T*. Earth's magnetic field is approximately $5*10^{-5}$ *T* or about *0.5 G*. Because magnetic fields can be very small most magnetometers give data in units of *μT*. Magnetometers can also be affected by objects in the environment and because of their sensitivity lose accuracy. Regardless of this, magnetometers have many applications in navigation, environment monitoring, and even medical devices.

3.3.4 Inertial Measurement Unit (IMU)

All the above sensors can be packed into one sensor called an inertial measurement unit (IMU). The IMU can be used to measure a bodies' orientation and motion in space. Although an IMU is one unit it is made of individual sensors usually: accelerometer, gyroscope, and magnetometer. Not all are required; usually an accelerometer and gyroscope are used with a magnetometer being optional. We can use an IMU to sense all our criteria such as sudden acceleration spikes, angular data in case the bike were to fall, and use the magnetometer as a compass.

3.4 Bluetooth Modules

For this section we are taking a look into the technology of the Bluetooth module. We will speak on some introductory information on what is Bluetooth and what a Bluetooth module is. Then give some insight in some of the features that we deemed to be important for our design specifications.

3.4.1 - What is Bluetooth?

Bluetooth is a technology that wirelessly uses radio waves to transmit high-data information across short distances. With our current technological capabilities as a society, ease-of-use of Bluetooth and the technology that integrates it has increased to incredibly abstract levels; so much so that people that describe themselves as “technologically inept” or something similar can utilize this technology. It is commonplace in the modern world, almost to a point where most people depend on it.

Bluetooth can connect any kinds of devices to each other, as long as these devices integrate Bluetooth technology and have data to transmit along it. If one is a smartphone user, Bluetooth can connect their smartphone to an enormous number of different devices. Speakers, televisions, lights, other smartphones, etc.

The group has planned and is currently planning on utilizing Bluetooth technology. This would be done by integrating a Bluetooth module into our main PCB, and then engineered to transmit and receive information from a connected smartphone.

3.4.2 - Bluetooth Modules

Bluetooth modules are exactly what the name may suggest: finished module circuits that, when integrated with other technology, can enable the use of Bluetooth within whatever the module is fitted into. Rather than having to come up with a way to implement this technology by making our own circuit, Bluetooth modules simplify this process. The group’s goal is to achieve a Bluetooth connection with a smartphone and respective application. How this is achieved is not necessarily a factor.

According to mokoblue.com, Bluetooth modules have a maximum communication range of around 100 meters (about the length of a football field). This range classifies Bluetooth connections as short-range communications. This is an ideal specification for the group’s application, since a communication technology is required that can send high amounts of data over a short distance; it is assumed that the connected smartphone would be carried by the operator of the e-bike.

When selecting a Bluetooth module to use for our project, there are multiple things to consider. Included in these things are the Bluetooth module’s application and transmission distance, which were already considered previously; both the application and transmission distance are compatible with almost all Bluetooth modules. Among other things to consider are power consumption, technical documentation/support, and, since we live in the wonderfully moist state of Florida, we must also consider the moisture sensitivity of these modules.

Figure 10: A Bluetooth module (Copyright pending)

3.4.3 - Power Consumption/Output

Power consumption and power output are both incredibly important specifications to consider when selecting a Bluetooth module. Having the incorrect power consumption information could mean that your hardware will fail; parts could not function properly because they’re not getting enough power, or they can become damaged after receiving too much power.

The group is considering both specifications for the project. When considering power consumption, having a smaller power consumption will be ideal. The e-bike is just that: an electric bicycle. It is dependent on the electricity that can be provided by the battery we select. Having components that use less power where they are able will be invaluable to the longevity of the e-bike, both in the short term and long.

The output (transmit) power of the module is measured in dBm (decibel meters). The units scale similarly to decibels, with increases in the units being exponential rather than linear. The modules listed after performing a quick search on Mouser Electronics reveal that modules commonly operate within the +10 to +20 dBm range. In our case, as previously mentioned, the range will not be very far as the operator of the e-bike will be within operating distance (which typically means sitting on or driving it in some capacity). Opting for the lowest transmit power that achieves the functionality we require would be ideal; so far that seems to be the +10 dBm models.

3.4.4 – Communication Connection

When selecting a Bluetooth module to use, something to consider is how the module is going to communicate with other technologies. There are two main options for this: an antenna or using a radio frequency (RF) pin on the Bluetooth modules. The RF pin can be used to pair with coaxial technology (like a coaxial TV cable) to communicate. The group has opted to find a Bluetooth module with a built-in antenna to make that part of the process easier.

3.5 Voltage Regulator

For this part of the text, we are conducting research on the different types of voltage regulators. Looking at two types of voltage regulators and seeing how they work. Also discovering the purposes of each and why they would benefit our needs.

3.5.1 Linear Voltage Regulator with Low Dropout

Without the need of an inductor, linear regulators are a straightforward way to use an integrated circuit to regulate a higher voltage to a lower voltage. Due to their simplicity and low price, linear regulators can be widely used in today's electronics and have a wide range of specialized applications. The dropout voltage is the smallest voltage that must exist between the input and desired output voltage for the linear regulator to function properly. The linear regulator enters dropout mode, where it stops regulating the input voltage and the output voltage tracks the input voltage, if the voltage difference between the input and output is less than the specified dropout voltage.

The benefit of using linear regulators with lower dropout voltage is that they can regulate input voltages more closely to the desired output voltage. In other words, the closer the input voltage can be to the output voltage while preserving regulation, the lower the specified dropout voltage. LDO linear regulators regulate the input voltage from a source, such as a battery, into a lower output voltage that may be used by a device on the load side, typically a microcontroller. Voltage regulation is achieved by the two main LDO architectures, PMOS and NMOS. LDOs achieve voltage regulation regardless of architecture thanks to a feedback loop that enables the circuit to regulate the drain-to-source resistance.

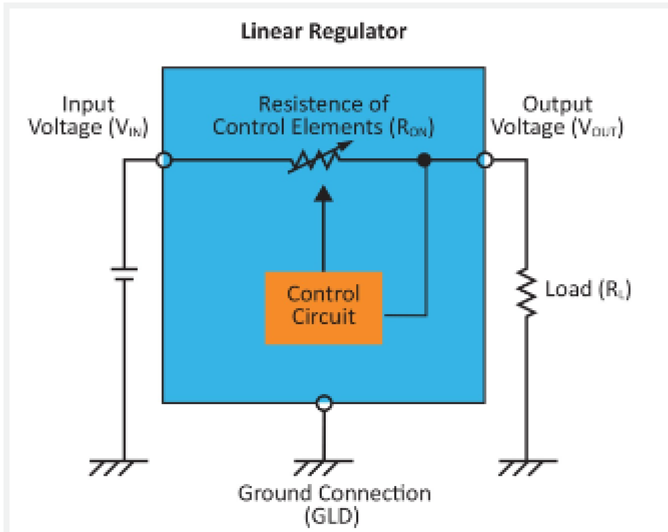

Figure 11: Linear Voltage Regulator with Low Dropout

3.5.2 Switching Regulators

Due to their high efficiency, compact solution sizes, and versatility to step-down, step-up, or invert voltages, switching regulators are currently the most often used type of DC/DC power conversion. As implied by its name, switching regulators regulate the turning on and off, of a switch (transistor) to move energy from its input to its output. Some important additional elements required in a switch design include inductors and capacitors for energy storage and diodes for controlling the direction of currents. The magnetic field of the inductor stores and releases energy as the switch cycles on and off. Switching regulators can effectively transform power by controlling how much energy is kept or released by the inductor.

3.6 Motors

In this section we will be going over the type of motor in which we plan to use for the design. Explaining the components in which you can find within the motor and features. Essentially giving a description of the inner workings of the motor and what each component does within the system. Then explain differences in motor types that will lead into the selection of the motor that is being selected for the design.

3.6.1 Brushless Direct Current Motors

Brushless Direct Current motors, also known as BLDC motors, are beginning to grow in popularity and are being implemented in many industries such as medical, industrial, and automotive. Brushless Direct Current motors are electronically commutated rather than using brushes for commutation, as the name suggests. Compared to brushed DC motors and induction motors, Brushless Direct Current motors have many advantages. Some of these advantages are:

- Higher speed ranges
- Higher dynamic response
- Long operating life
- Noiseless operation
- High efficiency

Also, because of the increased torque-to-motor-size ratio, it can be used in applications where weight and space are important considerations. Brushless Direct Current motors can be a type of synchronous motor which indicates that the magnetic fields produced by the stator and the rotor revolve at the same frequency. These motors can be found in three types of configurations which are single-phase, 2-phase, and 3-phase. The 3-phase configuration has grown in popularity and is widely used for different applications. Two major components of a Brushless Direct Current motor are the stator and rotor. Compared to brushed DC motors and induction motors, Brushless Direct Current motors have benefits. They offer improved speed-to-torque characteristics, high dynamic responsiveness, high efficiency, extended service life, silent operation, wider speed ranges, and more. Also, since more torque is provided to the motor size, it is advantageous in applications where weight and space are important considerations.

3.6.2 Stator

A Brushless Direct Current motor's stator is made up of stacks of steel laminations with windings inserted into slots axially cut along the inner periphery. The stator typically resembles that of an induction motor, although the distribution of the windings is different. Three stator windings are often connected in a star pattern in Brushless Direct Current motors. Three stator windings are often connected in a star pattern in Brushless Direct Current motors. Each of these windings is made up of several coils joined together to form a winding. A winding is created by inserting one or more coils into the slots and connecting them together. To provide an even number of poles, these windings are placed evenly across the stator's periphery.

Two types of stator windings that are seen in Brushless Direct Current motors are sinusoidal and trapezoid. In the corresponding types of motor, the phase current likewise exhibits trapezoidal and sinusoidal variations. Because of this, a sinusoidal motor's torque output is smoother than the trapezoidal counterpart. The sinusoidal motors' dispersion of coils around the stator's periphery necessitates more winding interconnections, which raises the cost because more copper must be absorbed by the stator windings.

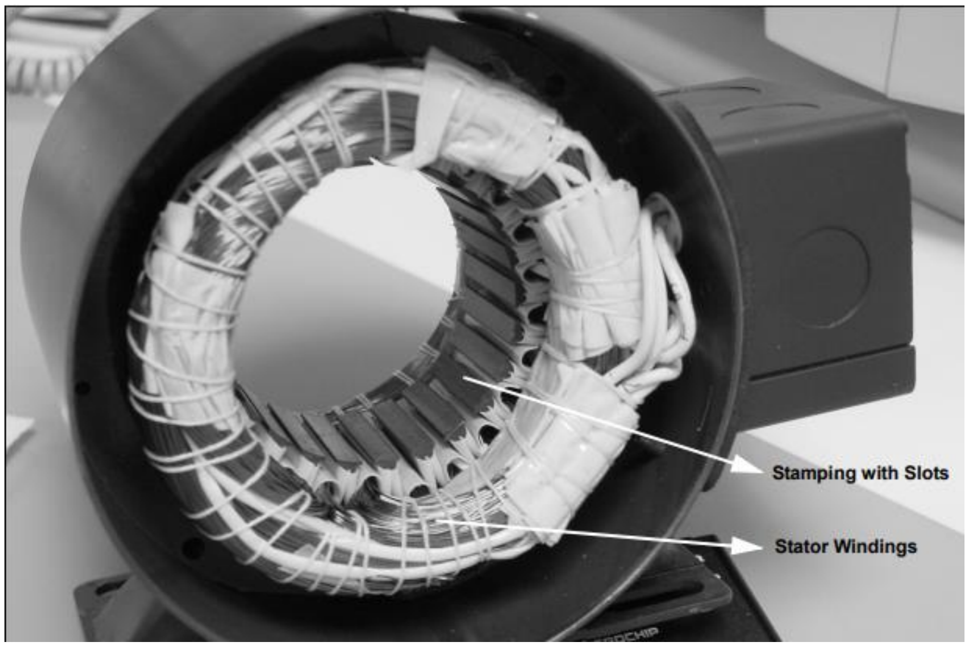

Figure 12: Stator of a Brushless Direct Current Motor (Copyright pending)

In addition, it can be seen that the distinction between the two motors is dependent on the interconnection of coils in the stator windings that give the different types of Back Electromotive Force (EMF). As the Brushless Direct Current Motor rotates the generation of a voltage called the Back Electromotive Force is created. This voltage is in opposition to the main voltage supplied according to Lenz’s Law. Below are figures of the Back Electromotive Force in respect to their names.

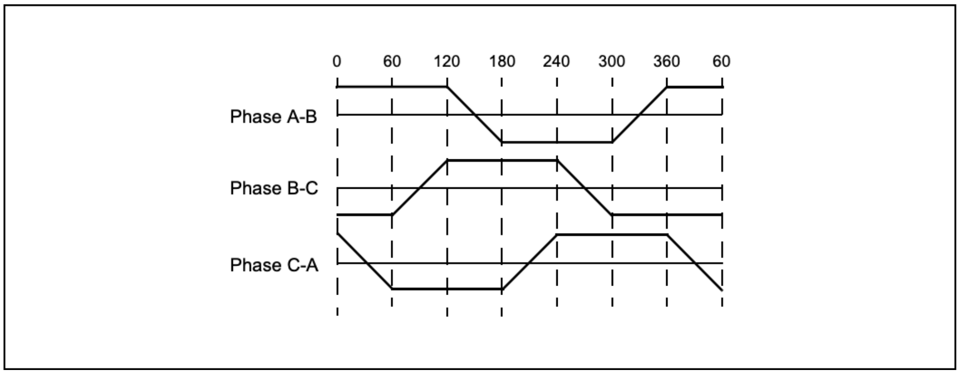

Figure 13: Trapezoidal Back Electromotive Force (Copy pending)

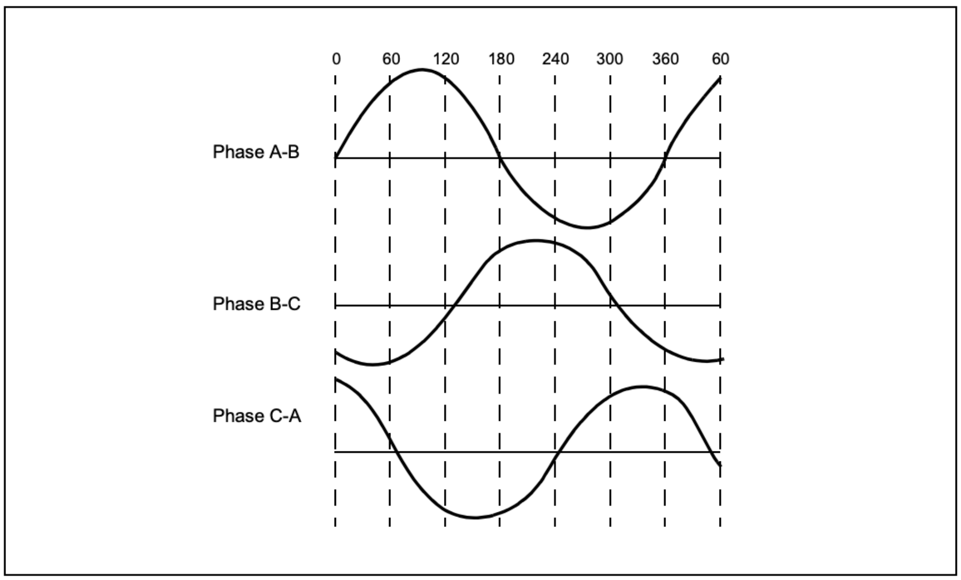

Figure 14: Sinusoidal Back Electromotive Force (Copyright pending)

3.6.3 Rotor

The rotor is built of a permanent magnet and has alternate North and South poles in pairs ranging from two to eight. The appropriate magnetic material is selected to manufacture the rotor based on the desired magnetic field density in the rotor. Permanent magnets are often created using ferrite magnets. Magnets made of rare earth alloy are growing in favor as technology develops. Although ferrite magnets are less expensive, they have a low flux density for a given volume, which is a drawback.

The alloy material, on the other hand, has a high magnetic density per volume and allows the rotor to compress deeper while maintaining the same torque. Moreover, compared to ferrite magnets, these alloy magnets provide more torque for the same size motor. Examples of rare earth alloy magnets include those made of neodymium (Nd), samarium cobalt (SmCo), and neodymium, ferrite, and boron (NdFeB). Research is ongoing to increase flux density and further compress the rotor.

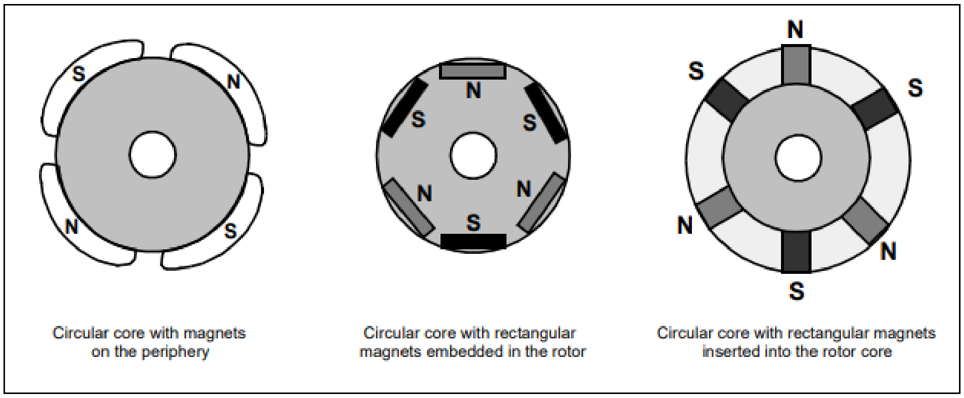

Figure 16: Rotor Magnet (Copyright pending)

3.6.4 Hall Sensors

A BLDC motor's commutation is electronically controlled in contrast to a brushed DC motor. The stator windings should be activated sequentially to turn the BLDC motor. Understanding which winding will be powered after the energizing sequence depends on knowing the position of the rotor. Hall effect sensors built within the stator are used to determine the position of the rotor. On the non-driving end of the motor, the stator of most BLDC motors has three hall sensors included into it. The hall sensors provide a high or low signal whenever the magnetic poles of the rotor get close to them, indicating whether the north or south pole is doing so. The precise commutation order can be calculated using the combination of these three hall sensor signals.

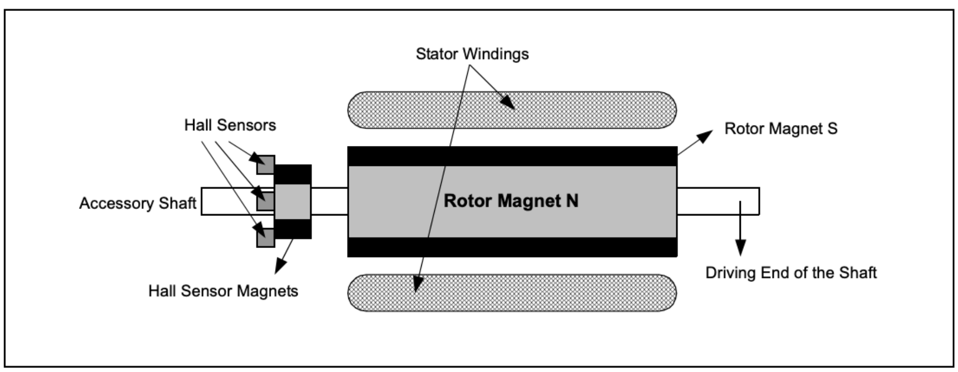

Figure 15: Tranverse Section of a BLDC Motor (Copyright pending)

A BLDC motor with an alternate north and south permanent magnet rotor is shown in transverse in the following figure above. The stationary portion of the motor contains Hall sensors. Because any misalignment of the Hall sensors with respect to the rotor magnets will result in a mistake in determining the rotor position, embedding the Hall sensors into the stator is a difficult task. Certain motors may include the Hall sensor magnets on the rotor in addition to the primary rotor magnets, making it easier to place the hall sensors onto the stator. They are a miniature duplicate of the rotor.

As a result, the hall sensor magnets have the same impact as the primary magnets whenever the rotor turns. Typically, the hall sensors are fastened to the enclosure cap on the non-driving end by being installed on a PC board. This gives customers the ability to align the entire hall sensor assembly with the rotor magnets for the greatest performance. There are two different forms of output depending on where the hall sensors are physically located. The phase shift between the Hall sensors can be 60 degree or 120 degree. Based on this, the manufacturer of the motor specifies the commutation sequence that must be used while operating the motor.

3.6.5 Sensored 3-Phase BLDC Motor Control Using Sinusoidal Drive

One of the most popular ways to drive BLDC motors in industrial applications has been the sinusoidal current drive. The sinusoidal current drive offers more efficiency, less torque ripple, and reduced acoustic noise when compared to the six-step commutation (trapezoidal drive). Users favor it as their top choice for low-speed, low-noise motor control systems. The maintenance and implementation costs must be taken into account when selecting the appropriate motor type and motor controller for practical applications.

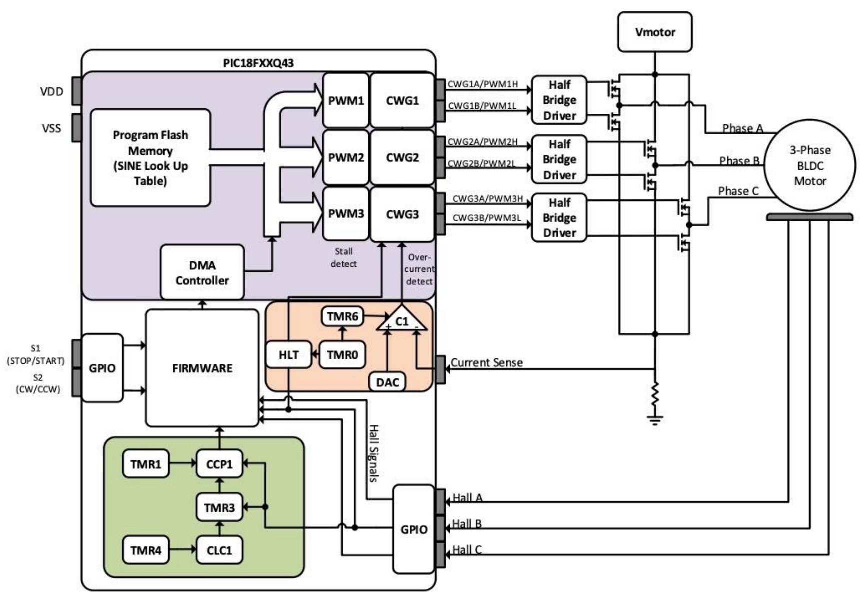

Figure 16: 3-Phase BLDC Motor Control Block Diagram (Copyright pending)

3.6.5.1 Sinusoidal Current Drive

The fundamental idea behind the sinusoidal drive is to deliver sinusoidally varying currents to each motor winding according to the rotor position. In relation to the appropriate Hall sensor, these currents are 120 degrees out of phase with one another. The drive signals needed for BLDC motor control call for variable voltages that change according to the motor's speed and position. By employing a 16-Bit Pulse-width modulation (PWM) signal, this variable voltage is applied. The MOSFET driver receives sinusoid-based signals from Programmable Flash Memory modules, which are then used to create current on each motor winding. The sinusoidal drive's torque ripple is somewhat less than the trapezoidal drive's due to the applied voltage's steady change.

3.6.5.2 Angular Position Detector

When applying sinusoidal current drive, the angular location of the rotor is essential for producing waveforms that are synced to the motor. Since hall effect sensors can only detect an approximate position in an electrical cycle, they only provide limited information. Based on the precise rotor position, a continual change in applied voltage to the MOSFET driver is necessary to apply the sinusoidal current drive to the BLDC motor. To represent a unit angle of rotation in this application, a motor angular position function is used to split the hall signal into smaller signals. It separates the hall signal into shorter timescales, each of which serves as a trigger to adjust the applied voltage at a specific moment in time and place.

This function is produced via a number of peripherals, including timers and compare (CCP). This approach works by counting the amount of system clock ticks required to finish a hall period, dividing that number by the appropriate number of units for the subsequent period, assuming that subsequent period has the same clock tick count. Since it is essentially a hardware division, the calculations may include remainder clocks. Particularly when using a slower clock source, these residual clocks will be appended to the last degree/phase of the period. Use of a faster clock source helps to minimize these mistakes. In the figure below is a block diagram representation of a motor angular position scheme.

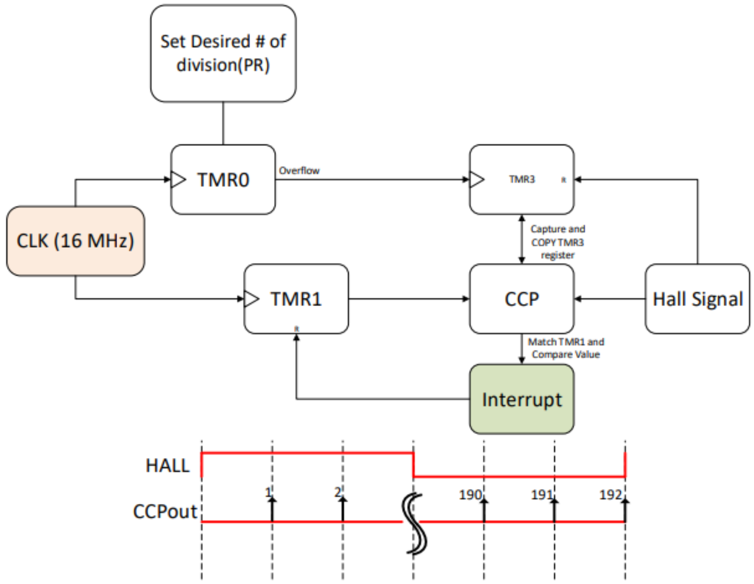

Figure 17: Motor Angular Position Detective Scheme (Copyright pending)

3.6.5.3 Fault Detection Control

This system employs fault detection control to halt motor operation when a potential cause of motor drive failure is identified. Each detecting device should be turned on for a brief period of time after the motor starts up to prevent a false trigger. In this we can see the application of an overcurrent protection. The circuit may overheat or undergo system failure if it draws more current than is permitted due to commutation errors, an excessive load, internal defects, etc. An overcurrent detection is employed to prevent such circumstances. Monitoring the 3-phase MOSFET driver's bus current allows for overcurrent detection. The motor driver's low side has a tap on the shunt resistor (RSHUNT). As the voltage is exactly proportional to the current across the resistor, the voltage across RSHUNT represents the current flowing through the driver.

The voltage across the RSHUNT is continuously compared to the MCU's reference voltage. The comparator (CMP) input samples the bus current while the motor is running. The comparator output voltage is checked every 50 ms to see if it exceeds the Digital to Analog (DAC)-set reference voltage. The Complementary Waveform Generator (CWG) peripheral will be turned off and the motor will halt if the comparator output is high. Before the motor stabilizes, it draws a large amount of current during start-up. The motor might halt as a result of a false trigger from this. This problem is avoided by inserting a 500 ms delay after startup before turning on the fault detecting unit.

In addition to the over current detection there is also the stall detection that is component of the fault detection control. When the motor is running, the motor Hall sensor produces a steady periodic signal in the form of pulses. When these pulses are absent for an extended period of time, it means the motor has stopped or is in a stall condition. When the motor load torque exceeds the motor shaft torque, this scenario typically occurs. The motor draws more current than it is designed to during a stall state, which also results in overheating and motor failure.

A stall detection feature is also incorporated in order to recognize such a circumstance. A Hall signal must be present for a certain amount of time in order for the Hardware Limit Timer (HLT) of the TMR2 peripheral to detect its disappearance. It's programmed to run in rollover Pulse mode. In this mode, whenever a falling edge transition is discovered, an input signal is permitted to clear the TMR2 register. TMR2 will constantly advance until it reaches its maximum value, setting its Overflow bit, in the absence of a pulse or one with a lengthy periodic duration. HLT will cause an interrupt that stops the motor by turning off all CWG peripherals. The Hall B signal, which is coupled to the RC6 input, is used as the reference signal in this application.

In a typical configuration, the signal produced by the Hall sensor has a period of around 5 ms. The interrupt flag will be set if the timer counter matches the PR value. To detect the motor's stall situation, the PR value that will be set on TMR2 needs to be greater than the period of the Hall sensor signal.

3.6.5.4 Drive Signal Generator

For the DMA controller to quickly identify its address as the source, the sinusoidal data is split into six arrays. A single set of sinusoidal data can be used because all three windings need the same signal that has been phase-shifted by 120 degrees. There are 32 16-bit components per array. The Program Flash Memory (PFM) of the MCU houses these arrays.

The DMA source address is set using the DMA controller to the address of the first element. The PWM Duty Cycle register, which is predetermined as the DMA destination address, receives the data sent from the PFM. The size of the source address must be a multiple of the size of the destination address, and vice versa, according to the DMA controller. The size of the source is determined by the DMAxSSZ register, whereas the size of the destination is determined by the DMAxDSZ register. The DMAxDSZ register's value is equal to 2 bytes since the PWM Duty Cycle register is a 16-bit register. The array size kept in the PFM determines the value of DMAxSSZ.

The Hall state transition and the motor angular position interrupt are the two events that access or change the settings of the DMA controller. The firmware loads the DMA controller source address register in response to a Hall state change, depending on the sector position and orientation. The run-time DMA channel must be enabled and disabled in order to change the addresses while the system is in use. This requires a lock and unlock sequence. The DMA controller, on the other hand, is prompted by the motor angular position interrupt to increase the DMA source address, pointing to the next element in the array, until all of the elements have been loaded to the destination or another Hall state change has been detected.

The variable voltage is set in the PWM slice register, which is where each DMA channel's destination address points. The inductance of the motor affects the switching frequency for motor control applications. The switching frequency ought to be high enough to prevent core saturation if the motor's current may change quickly. As a result of the need to provide high frequency and high resolution for motor operation, the switching frequency in this application was chosen at 40 kHz. The CWG peripheral is used to operate the three-phase motor using sinusoidal currents. Three half-bridges—one for each motor terminal—make up the MOSFET driver of the three-phase BLDC motor.

Two switches make up each half-bridge; these switches require complimentary PWM signals. As a result, the CWG modules are set up in half bridge mode, which causes each of them to produce two output signals that mimic the input PWM's true and inverted forms. The CWGxB input is set up for the driver's low side switches, while the CWGxA input is set up for the high-side switches.

It is possible for both switches of a half bridge to turn on at once since power MOSFETs have a limited on- or off-time. A short circuit could result because it generates a low resistance channel from the source to the ground. It’s known as a shoot-through. To avoid shoot-through current during an output level transition, CWG inserts a dead-band delay. A temporal delay called a "dead-band delay" is inserted before the switch transition to stop the high and low-side switches from conducting at the same time. You can add dead-band delays to the input source's rising or falling edge. On the CWGxDBR and CWGxDBF registers, dead-band counters are set.

3.6.6 Geared Hub Motors

A geared hub motor has gearing inside of it to lower the high speed of a powerful and effective motor to the low speed of the wheel. A geared hub motor is typically wider and has a lower radius than a straight drive hub. They can have a variety of various internal configurations, but most typically they contain an outrunner motor that powers a planetary gear set attached to the rotor. The hub motor is straightforward to install and has the weight advantages of a transmission drive packaged into it thanks to the geared hub idea. They often weigh approximately 50% less than a direct drive machine of comparable power, and they frequently produce more torque. A conventional direct drive machine can only generate about 35 Newton-meters (N-m) of torque, however the German-made Heinzmann can generate up to 80 N-m.

A freewheel is within almost all the available geared hub motors. This eliminates the possibility of regenerative braking but implies that there is very little rolling friction to spin the wheel when the motor is off. Weighing these benefits of the geared hubs against their drawbacks is necessary. In general, geared hubs are more expensive, have several moving parts that are prone to wear, and make audible noise. Whereas geared hub motors with various speeds are theoretically possible, every device on the market right now only has a single speed. Some people fervently contend that e-bikes ought to feature a variety of transmission ratios so that the same 500-watt motor may both propel you slowly up a 15-degree hill and propel you quickly along a flat surface while always functioning in the vicinity of its peak efficiency zone. Yet if the market is any guide, the additional prices and difficulties from multi-speed drives surpass their advantages.

3.6.7 Direct Drive vs. Geared Hub Motors

In the table provided below is a general comparison of the Direct Drive and Geared Hub Motors. With the data that was collected and researched we came to terms with the categories in which we deemed to be important for our design specifications.

	Geared Hub	**Direct Drive**
Energy Efficiency	High Efficiency	Lower Efficiency
Torque	Higher in torque	Low in torque
Weight	Lighter in weight	Heavy in weight
Performance	Low performance	Higher performance
Price	Cheaper	Higher in price

Table 4: Comparison of Motor types

3.7 Throttle Controls

The following section is an evaluation of the different types of throttle controls that an operator can interact with to propel an e-bike. There are a few different kinds of throttles; each has their pros and cons and they should be weighed against each other to determine which is best for the project.

3.7.1 - What is an E-Bike Throttle?

According to the Oxford dictionary, the technical definition of a throttle is a device that controls the flow of fuel/power to an engine. Typically, the operator of a vehicle is the one that has access to the throttle. Although an e-bike does not have nor requires fuel to operate, it does require power and a device to control how much power is provided. This device is what the operator uses to propel the e-bike and control the power flow to the motor. This specification is the reason why this device is classified as a throttle.

3.7.2 - Popular Throttle Types

If one has ever ridden a motorcycle or an electric scooter or anything of the like, they’ll know that the throttle on these vehicles is located at the handlebars. An e-bike's throttle is typically located at the handlebars as well for ease of access for the operator. Since it is typically located at the handlebars, the weight/size of this device is something to consider. If this device is too heavy, it can negatively impact the operator's intent on directional control. If this device is too big, then it will negatively impact the operator's comfort when operating the e-bike. To minimize the weight/area this device takes up, some compact designs for throttles have become popular. Of these compact designs, there are two to make note of:

1) Twist Throttle

The twist throttle is a throttle device located in the handle of the e-bike itself. This is identical to the throttle a motorcycle uses. The handle can be twisted; the more it's twisted, the more power is output, thus more acceleration is experienced. There are two types of twist throttles:

a) Half-twist throttle

Only the inner half of the handle can twist to control speed

Figure18: Picture of a half-twist throttle on an e-bike (copyright pending)

b) Full-twist throttle

The entire handle can twist

Figure 19: Picture of a full-twist throttle on an e-bike (copyright pending)

2) Thumb Throttle

The thumb throttle is located at the edge of either the left or right handle, fashioned in such a way that the thumb can comfortably rest on it. To engage the throttle, the operator presses their thumb down on the throttle’s tab.

Figure 20: Picture of a thumb throttle on an e-bike (copyright pending)

3.7.3 - Consideration for Project

Both throttle designs are popular in the e-bike community. Although, there appears to be a debate surrounding which design can be considered “better” than the other. This, one can assume, comes down to personal preference. When it comes down to which will be used in this project, that will be the result of the same debate: which is the design the group prefers. There are numerous things to consider when making such a decision, as either throttle choice has its pros and cons. Below is a quick list of these pros and cons for each of the throttle types.

Twist throttle pros and cons:

- Pros
  - Allows for the operator’s entire hand to maintain contact with the handle
  - Can be more comfortable over long distances over the thumb throttle, as long as frequent speed changed are not required
- Cons
  - If frequent speed changes are required, then constant adjustments must be made; this can introduce wrist fatigue
  - May give uneven handle feeling, as the throttle handle may be much bigger than the other handle
  - May be difficult to implement, as an entire handle must be replaced
- Half twist vs full twist
  - Half twist
    - Pros
      - Smaller than full twist, more compact
      - Less accidental engagements
    - Cons
      - May be the most difficult to attach
      - May not be as comfortable as full twist
  - Full twist
    - Pros
      - Larger than full twist; better control
      - May be easier to attach to e-bike
      - May be more comfortable for hand
    - Cons
      - Prone to accidental engagements when running to wall/object

Thumb throttle pros and cons:

- Pros
  - Will not introduce wrist fatigue with constant speed adjustments
  - Easier to implement; a thumb throttle attaches to the handlebar as is

    - Prevents uneven handle feeling as both handles will be the same size
- Cons
    - May be less comfortable over long distances, as the thumb is doing all the work to maintain speed
    - Operating e-bike over difficult, bumpy terrain can impact operator's reliability to maintain speeds
        - If the bike goes up and down, so does the thumb

If the group decides they want to focus on giving the e-bike a sleek and minimal look/feel or are more comfortable with twisting their wrist, then the twist throttle should be considered.

If the group decides they prefer a static hand grip and are uncomfortable with twisting their hand, then the thumb throttle should be considered.

Throttle Type	**Comfort**	**Implementation Ease**	**Grip Rigidity**
Thumb	Low	High	Low
Half-Twist	High	Lower than Thumb	High
Full-Twist	High	Lower than Thumb	Higher than half-twist

Table 5: Types of Throttle

3.8 Torque arm

Torque arms are used in hub motors in order to prevent there being axle rotation. Essentially with the torque being generated one way there is an equal amount of it in the opposite direction. Most electric bike hub motors have flats carved into the axle that fit into the dropout slot and provide some rotational stability. Nonetheless, in high power systems that generate a lot of torque or in designs with weak dropouts, the forces present may be greater than the material strength and push the dropout open. The axle will spin freely in that scenario, possibly causing the wheel to fly off the bike and wrapping and severing the motor cables. When looking for a viable option for the torque arm there are some factors in which to take in account. The material in which you are looking for is stainless steel for how strong and durable it is. Next being the thickness of the torque arm needs to be looked at when selecting it. In most cases thicker is better so that it is able to have more of an effect in the design. An estimated measurement that is recommended is about a quarter inch or 0.635 cm. Lastly is the length in which the axle is from the point where the torque arm is mounted to the frame. Greater the distance equates the amount of force that is being resisted on the torque arm.

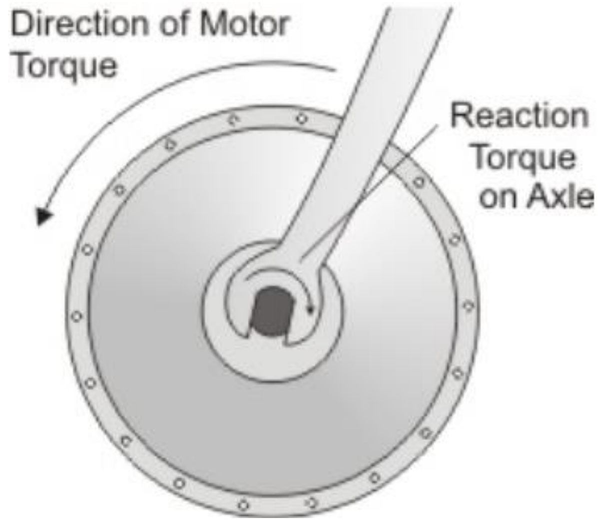

Figure 21: Torque Arm (Copyright pending)

3.9 Brakes

Brakes are used as a way to slow down objects that are in motion that need to stop. There are many different types of brakes used on bicycles, however, only two are widely used which are rim brakes and disc brakes. There are three more brakes used by bicycles, however, they are not as common as the previous two so the information given for those brakes will not be as in depth compared to the first two. We may need to replace ours with due to the fact that the brakes currently on our bicycle was not designed to stop someone using a motor to propel themselves.

The companies REI and bikeradar state that the most common type of brakes on bicycles today are rim brakes or disc brakes. They each have different opinions on which brakes are used on bicycles other than the two stated above. REI states that coaster and drum brakes are also used on bicycles while bikeradar states that V-brakes are used. The safety standards for all of the brake types will be found in 4.0 related standards and design constraints.

3.9.1 Rim Brakes

These brakes use the rim of the wheel in order to apply a force to slow down and to stop. They are simple using only a wire on the bicycle we currently plan to use for the project. Currently rim brakes can cost anywhere from $10 up to $544. This wide range of price is most likely because of materials used or if a company has a sort of “elite” status like Apple™ has.

These brakes have upsides and downsides as with any item with an upside being a lower cost compared to other brakes. The downsides consist of poor performance when it rains, which is common occurrence in Florida depending on the season. There are also issues of mud and snow with snow being a non-factor in Florida. There are different types of rim brakes that can be used and the main difference between them is the way the force is applied. For example, a rod-actuated brake uses rods and pivots to apply force on the rim when the brake is squeezed to apply pressure. The one on the bike that is being planned to be used are called side-pull caliper brakes but those also have a subdivision with one being a single-pivot side-pull caliper brakes and the other being a dual-pivot side-pull caliper brakes. Below is the type of brake currently on the bike.

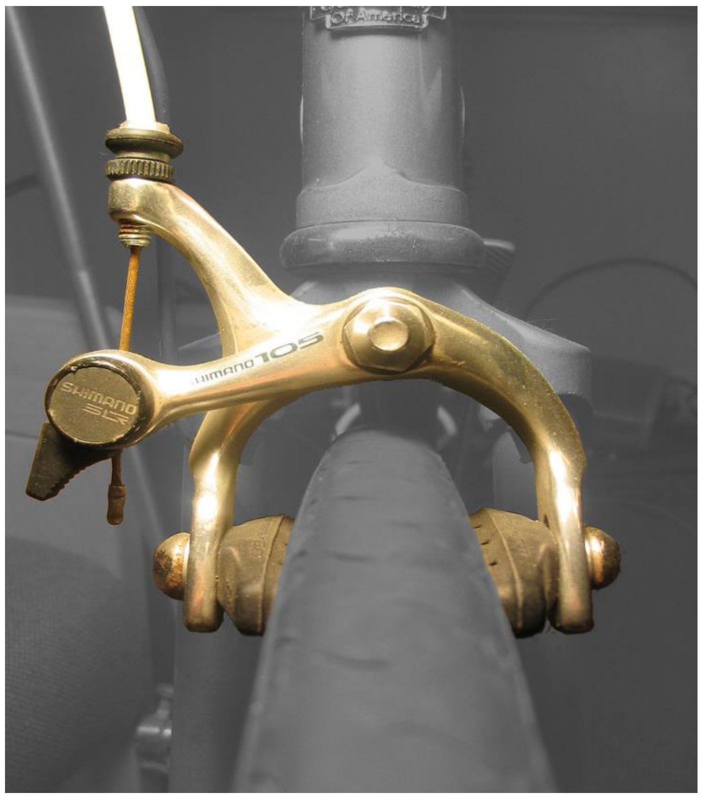

Figure 23: Single pivot-side-pull caliper brake

These are brakes that are generally used on narrow tires because with a wider tire the force applied decreases.

3.9.2 Disc Brakes

These brakes are attached at the wheel hub of the tire that rotates along with the tire. While rotating a force can be applied to the disc to slow or stop the bicycle. These brakes are considered to be better than rim brakes because they are higher up from the ground, meaning they are farther from dirt. They also have a much easier time of replacing compared to rim brakes where only the disc must be changed out. A disadvantage is the heat because of the smaller surface area depending on if you need a small one compared to rim brakes. This also means that it is possible to use a rim brake that is made of a material that is superior to rims at heat dissipation, but this may increase cost. Florida can have very hot summer days which would not be advantageous to these types of brakes assuming we use a smaller one to help increase the speed of the e-bike, but the better performance in the rain may make up for that fact. An example of a dick brake is below.

Figure 24: Hydraulic disc brake

The reason for the holes in the disc is to help reduce weight. While rims are inherently part of the design on a bicycle (the wheel) a disc brake is an addition to the bicycle that must be added to after the fact. This would not be the best when we are trying to make the e-bike have a higher speed and would have a higher drain on the battery.

3.9.3 Coaster Brakes

A coaster brake is engaged when the pedal is rotated in the opposite direction, an amount that can be changed depending on the distance between the clutch and the driver side expander. During normal operation (moving forward) the clutch grabs onto the casing so the wheel and casing are moving in sync. When back pedaling the clutch goes along a thread to push against the driver side expander. This expander goes inward pushing internal plates up against the casing which causes friction against the container slowing you or stopping you.

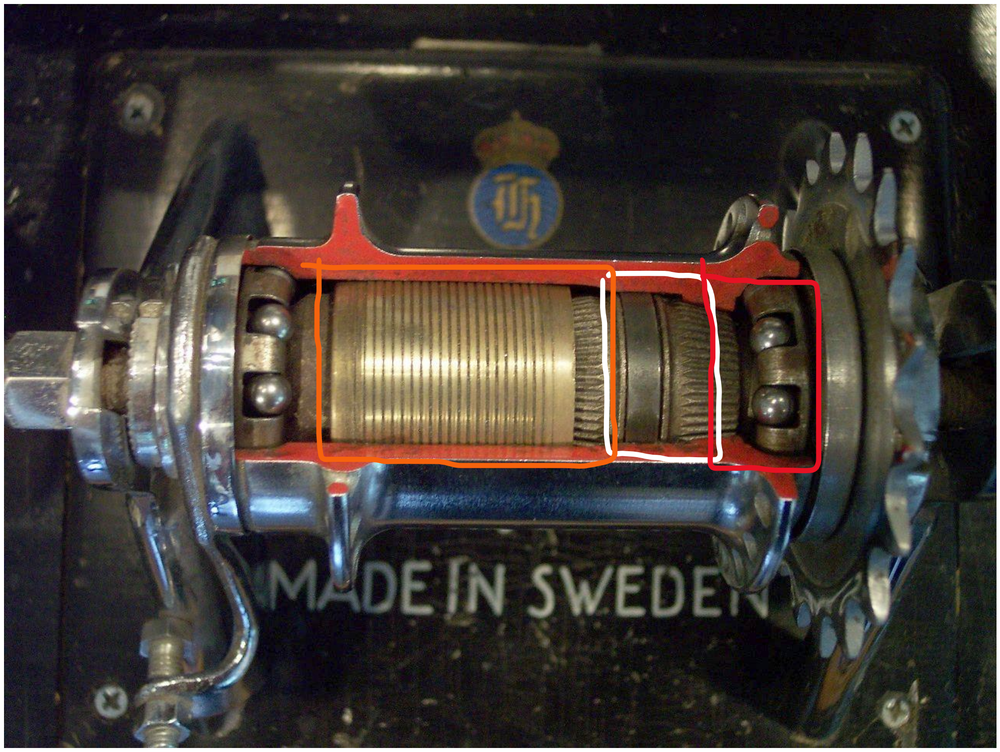

Figure 25: Inside a coaster brake

In the picture above the red square is the clutch which has teeth that grabs onto the white box (driver side expander) which then pushes the orange box (brake pads). The brake pads have a slope on the underside of them so when the clutch is not engaged, they rest on top of the expander and apply no force to the container. To disengage the brakes going forward with the pedals release the brake pads.

3.9.4 Drum Brakes

These can also commonly be seen on cars and use a wheel cylinder to push the brake pads (also called shoes) against the drum to apply the friction required to slow or stop. This is similar to the coaster brake in that they both push metal on metal to stop or slow down. The drum brakes, however, use springs in order to disengage the brake pads from the drum.

In a vehicle hydraulics are used to engage the brakes but in a bicycle, cables are used instead.

Figure 26: Internal of a drum brake

In the picture above the black are the brake pads while the red is the wheel cylinder.

3.9.5 V-Brakes

This brake is a subset of rim brakes that applies the force to the rim in a different enough way to get its own name and because of a trademark by Shimano. These work by pulling the pads to the rim through a cable above the tire while the rim brakes above in 3.9.1 more so push the pads onto the rim.

Figure 27: Figure of a V-brake

Above is an example of a v-brake with the cable riding across on the top.

3.10 - App

The group has decided upon building a multi-function smartphone companion application for the e-bike. This application will connect to the e-bike via Bluetooth and send & receive information to and from the e-bike. This will be made possible by the aforementioned Bluetooth module in section 3.4. The application will mainly behave as a heads-up-display (HUD) for the operator of the e-bike. The e-bike will feature a phone clamp on the handlebars and, along with the application receiving information, can be used as a visual display for certain statistics associated with the e-bike's function: current speed, remaining battery charge, and current battery usage, amongst other things.

There are different options for developing an application. The group can either opt to:

- Develop a web application that a smartphone can access via a web browser, or
- Develop an executable application specifically for the smartphone

Both options have their advantages, and both must be considered to find the best possible option for the group.

3.10.1 – Browser Web Application

With an application comes a technology stack that is used to build the application. A technology stack is a collection of technologies used to build an application. A stack is typically identified by either an abbreviation or a short phrase. For example: a LAMP stack. LAMP is an abbreviation used to identify the technologies: Linux, Apache, MySQL, and PHP. The abbreviation does not always identify the same scope for each letter.

When it comes to experience, however, there are two technology stacks the CpE group members are familiar with: LAMP and MERN stacks. When it comes to a certain stack that the group has mentioned may work the best for the project

When considering which one will function the way the group requires, any of the choices we come across are feasible. We are given freedom to use whatever technology we desire, though this technology must be something that can we are capable of using properly to achieve our goals. That being said, the main factor to consider when deciding which technology stack to use would be whatever the group is most comfortable with using.

3.10.1.1 – LAMP Stack

The LAMP stack, as previously mentioned, consists of Linux, Apache, MySQL, and PHP. Linux is used as the operating system (OS), Apache is web server software and is used to host the application, MySQL is used for databasing and storing information, and PHP is used for API calls between the UI and the database, sending and receiving information.

According to Amazon, the following five concepts are why a LAMP stack is an important contender for consideration when building an application:

- Cost
  - Cost is an extremely important factor when considering technology to use. Fortunately, all of the components of a LAMP stack are free. A developer is capable of downloading all the technologies and using them without spending a dime.
- Efficiency
  - LAMP is a tried-and-true tech stack that has been used numerous times. This can prove to be efficient, as the technologies are familiar to most developers, saving time to learn and set up.
- Maintenance
  - The maintenance of the technology involved with LAMP very good, as software experts from around the world contribute towards its development and maintenance.
    - There will still be maintenance on the developer's side for app-specific issues, but issues with the stack are well-maintained.
- Support
  - The number of developers around the world using LAMP is, to exaggerate, astronomical. The amount of documentation provided by its IT community can prove to be extremely useful, as experience is the best form of troubleshooting.
- Flexibility
  - The LAMP stack is flexible as certain technologies within the stack can be replaces by others. For example: Linux can be replaced by either Windows or MacOS to result in a WAMP or MAMP stack, respectively.

A LAMP stack would be a great option for app development, after considering the above reasons. However, to consider everything about it, not everyone in the group is familiar with Linux, since although it's a popular operating system, it is not as broadly used as Windows and MacOS are.

LAMP stacks are also better used for backend applications, ones that are hidden from end users. While DOM technologies can be incorporated into a LAMP stack to produce user interfaces (HTML, CSS), they are not explicitly included.

3.10.1.2 – MERN Stack

A MERN stack, similarly to a LAMP stack, is an abbreviation for the technologies used within its development. A MERN stack consists of the following technologies: MongoDB, Express.js, React.js, and Node.js. MongoDB is the database technology, Express.js a JavaScript web server framework, React.js is a front-end JavaScript library, and Node.js is a runtime environment.

Using similar factors to Amazon's evaluation of the LAMP stack:

- Cost
    - A MERN stack is not completely free, as MongoDB alone has a bit of cost to use, based on how much storage one requires. The other technologies are free frameworks/libraries open to use for everyone.
- Efficiency
    - The efficiency of a MERN stack is very high, as the web server, frontend, and runtime environment are all written in JavaScript.
- Maintenance
    - Maintaining a MERN stack application can prove to be quite simple since everything is written in one language. The learning curve begins with using MongoDB, as it is a document-based, no-SQL database. If one is primarily used to SQL databasing, this may prove difficult.
- Support
    - MongoDB is a company with a good support platform. They have entire websites dedicated to assistance for their customers. The JavaScript technologies in the stack would also prove to have good support as JavaScript is a very popular scripting language; the global IT community is very present in providing support for certain issues.
- Flexibility
    - The MERN stack is very flexible. Instead of using React.js for the frontend framework, once can opt to use Angular.js or even Vue.js, resulting in a MEAN stack or a MEVN stack.

3.10.2 – Smartphone Application

There are many things to consider when developing an application directly for a smartphone, with the most important factor being: which platform should the application be developed for: iOS, Android, or something else? For some, this is a simple answer: whichever they prefer the most. However, in this group's case, both iOS and Android platforms are an option as the group holds access to both.

3.10.2.1 - Platform

The platform that the application is developed for is incredibly important for development. Popular platforms that are available for development are iOS and Android; these two options not only dominate the smartphone market, but also are the only two platforms that the group holds access to. Either one of these would be a great option for development, since these operating systems are developed by incredibly large corporations that provide fantastic tools to assist with development.

- iOS
    - iOS applications are developed with Apple's own programming language: Swift. Applications also rely on Apple's XCode tool for development, which, apparently, is easy to work with. The unfortunate thing here is that XCode does not run natively on Windows computers, so either a Mac would be required for development, or a virtual machine running macOS.
- Android
    - Androids depend on Android Studio for development, which was introduced by Google in 2013 and has continued to be a frontrunner for Android app development for almost that entire decade. Android studio uses the Kotlin programming language to develop applications. An advantage of Android Studio is that it, while utilizing a plugin, can develop cross-platform applications for both iOS and Android devices.

3.10.2.2 – Flutter and a BaaS

One thing that the previously mentioned technology stacks have in common is their incredible ability to develop web applications. One thing they specifically lack, however, is the ability to port the web applications into mobile smartphone applications. Not only is this portability an issue, but also being able to port the web application to multiple different platforms.

This is one of the main advantages of Flutter. It is a UI framework developed by Google that uses its own Dart programming language, which is also developed by Google. Flutter is capable of compiling developed applications for multiple different instruction architectures; in the scope of this project, using Flutter would mean developing an application for iOS and Android devices at the same time. This would prove extremely useful since the group does not all share the same operating system on their smartphones, so using a technology that compiles into both operating systems enables the application to be more inclusive with testing.

Alongside Flutter would be a Backend-as-a-Service (BaaS). A BaaS is a simple way for developers to automate certain backend development processes and provide a cloud infrastructure management that is simple to work with. There are many choices for a BaaS to pair with Flutter. There are a few that are popularly used and are worth considering:

- Back4App
- Parse
- Firebase
- Backendless
- AWS Amplify

The above options provide similar functions to each other, while all having similar price points. These options are not free but are worth seriously considering, as streamlining app development for a negligible price tag seems more than worth it.

Approaching Flutter and BaaS similarly to the other tech stacks:

- Cost
    - Will cost more than the other two listed options.
- Efficiency
    - May be less efficient in learning to use the technology, since both Flutter and Baas are new concepts to the group. However, once enough learning has been done to develop, development efficiency would be unparalleled, considering the automation capabilities of a BaaS as well Flutter’s compilation into multiple architectures.
- Maintenance
    - Depending on which BaaS would be selected for the pairing with Flutter, there would be incredible maintenance for these technologies. For example: if Firebase were selected. Both Flutter and Firebase are developed and maintained by Google. AWS Amplify is developed and maintained by Amazon.
- Support
    - Google invested a lot of its resources into Flutter; it can be assumed having a great support team is part of this investment. The same applies to the BaaS options as well, regardless of which one it is.
- Flexibility
    - Contrary to the other great evaluations, the flexibility of Flutter is very low, if there’s any at all. Dart is a programming language unique to Flutter, so applications developed on Flutter would have to stay on Flutter.

Using a ranking system of 1, 2, and 3 to rank the solutions on a comparison table (1 being the most optimal):

Technology	**Cost**	**Efficiency**	**Maintenance**	**Support**	**Flexibility**
LAMP	1	3	2	2	1
MERN	2	2	3	3	2
Flutter, BaaS	3	1	1	1	3

Table 5: Comparison Table of Browser Web Apps

3.11 – Lights

On most vehicles found today exist lights to some degree. Whether they are lights on the front of the vehicle to illuminate the forward surroundings of the vehicle operator for clarity, or whether they are indication lights found elsewhere on the vehicle to indicate to others the direction the vehicle is going.

The group has decided that that placing not only front-facing illuminating lights but also indication lights on the e-bike is ideal. Not only is this ideal for operating a vehicle, it is also required by Florida state law, which states that bicycles must exhibit a white light on the front and a red light & reflector on the back. While operating an e-bike can be considered fun and entertaining, it must be safe not only to the operator, but to the operator's surroundings as well. Lights to illuminate the road ahead of the operator and to indicate deceleration (brake lights) are going to be implemented. Lights to indicate change of direction/turning (turn signals) can be implemented if time allows.

There are two common technologies used to produce light: incandescent light bulbs or light emitting diodes (LEDs).

3.11.1 Incandescent Bulbs

Incandescent bulbs are the bulbs that are found most in vehicles as well as households. These bulbs consist of a glass bulb with a filament inside hooked up to a circuit that applies a current to the filament. The filament then heats up to a significant temperature (around 3500° – 4500°F) and radiation is emitted from the filament. This radiation is in the form of visible light. The term "incandescence" means to obtain light from heat.

Because of the functionality of incandescent bulbs, their total lifespan can be relatively short compared to other lighting technologies (around 1,200 hours). Not only is their lifespan very short, but they are also notoriously power-inefficient. This group's e-bike is dependent on a single battery to operate everything electricity-based, so power efficiency is and incredibly important factor to consider.

Figure 28: A pair of incandescent bulbs (Copyright pending)

3.11.2 Light Emitting Diodes (LEDs)

Light emitting diodes (LEDs) are indeed a common lighting solution, however a smidge more expensive. LEDs consist of a semiconductor diode that produces light when a current is passed through it. Heat is generated in this scenario as well, but most LEDs implement heat sinks to pull heat away from the diode itself. LEDs capability to manage its thermal output is a significant factor in how long their lifespan is, which, compared to incandescent bulbs, is roughly 20-150 times longer (based on an average lifespan of 25,000 to 200,000 hours).

Not only do LEDs provide a longer lifespan, but they are also more power efficient. As previously mentioned, power efficiency is incredibly important to this project, as everything is being powered by a single battery. Since LEDs not only last longer but also are more efficient than incandescent bulbs, they would be wiser to select these when implementing lighting systems onto the e-bike. Even though they do cost more than incandescent bulbs, the money will be well spent.

Lighting Solution	Cost	Efficiency	Lifespan
Incandescent Bulbs	Low	Low	Low
LEDs	Relatively higher	Vastly higher	Vastly higher

Table 6: Lighting Comparison

Figure 29: A single, standalone LED (Copyright pending)

Figure 30: An LED strip (Copyright pending)

3.0.1 Part/technology selection

3.1 Battery selection

Currently most options consist of Lithium-Ion batteries because of their low discharge rate, higher voltage output, and high energy density. Therefore, the market is saturated with lithium-ion batteries and the only other option would be a set of nickel-metal hydride cells in series to get the needed voltage and has a higher rate of discharge compared to a Lead-acid which has fewer charge cycles which would not work for this application. This would require more work than is in the scope of this project so will not be done and will instead use the readily available lithium-ion batteries. Below will be a comparison of the two battery chemistry types that will be used and the other option that could be used if there was a more market availability.

Seeing as the motor (in 3.6) has a power maximum of 700 watts, but is expected to be 250-350 watts, a 36-volt battery with a limit of 9.5 amps would produce 342 watts to attempt to stay under the max nominal power. If the battery outputs at 24 volts we would keep the amperage at around 14 amps for a wattage of 336 which would be below the 350 watts. We limit the amps to ensure the e-bike does not go above the speed that would make the e-bike a class three.

	Lithium Ion	**NiMH**
Market availability	High	Zero
Discharge rate	Very low	Has a range from very low to low
Voltage	Around 3.6	Around 1.2
Cost	Very high	Medium
Energy density	Very high	Medium

Table 7: Battery options comparison

From the table of differences above a lithium-ion battery pack is the only choice though would be the best choice given how this battery will be used. It will need to be reliable with a low discharge rate while idle and not in use. The energy density will also help with any distance issues that may have arisen if the NiMH chemistry had been used.

The battery we could use is the *36v 20Ah Unit Pack Power e-bike battery*. This would give us the voltage needed to power the motor and would be able to run the motor continuously for around two hours assuming we limit the amperage to the 9.5 amps that was calculated earlier. The battery will allow the motor to get the necessary power to not only run for two hours but will also have the capability to allow the motor to go up a slight incline while maintaining a higher speed.

Figure 31: The battery pack for e-bike

The max current discharge for this item is 25A which is higher than the current we plan to take from the battery pack and also give us room to also ensure that the other components can be powered. The other components include the microcontroller which will allow us to run the Bluetooth module for the app.

The other option is much cheaper but if something breaks with the item it has a much longer return time of around two months. It is essentially the same thing.

3.2 Microcontroller selection

There are many kinds of microcontrollers for different cases with diverse programming options. The expected MCU pins and peripheral requirements are listed in the table below. Speed will also need to be taken into consideration since controlling the motor and sending different communication protocols simultaneously could cause slowdown and unexpected behavior.

Function	Number of pins	Protocol or Peripheral
Motor driver	6	PWM
Motor sense/feedback	3	Interrupts
Bluetooth module	2	Serial (RS-232)
Throttle	1	Analog/Digital
Brakes (Front and Rear)	2	Analog/Digital
Battery monitor	1	Analog
IMU	2	I2C
Lights	5	GPIO

Table 8: MCU requirements

Based on the investigation the list of possible MCUs are shown in the table below. These were selected as options based on availability, programming interface, and use case.

MCU company	MCU	Programming Interface	Programming Language
TI	MSP 430	JTAG	C
Microchip	dsPIC	PICkit	C
Atmel	AVR	JTAG / Arduino	C / Arduino
ARM	Cortex-M	JTAG	C

Table 9: MCU possibilities

Microchip’s *dsPIC33EV* is a good choice since it has built in support for BLDC motors and multiple PWM channels. At the time of this writing some dsPICs are difficult to find in stock so as an alternative the *STM32F4* family of Arm Cortex-M4 processors can be looked at. The *STM32F4* is the microcontroller of choice for the Vedder Electronic Speed Controller (VESC) which is an open-source project around better motor control.

3.3 IMU Selection

There are many IMUs on the market. A 9 degree of freedom (DOF) IMU with 3 axes accelerometer, gyroscope, and magnetometer are available and widespread on the market. Another thing to consider is converting the data from the IMU into useable information. The process to do this is outside the scope of this project. Fortunately, there exist IMUs with built-in microcontrollers that can do the processing on-chip and offload that to the IMU instead of the main MCU. The main MCU can then get relevant data from the IMU via interrupts or polling.

IMU	Features
BNO055	FusionLib software for absolute position
BNO085	SH-2 firmware with MotionEdge
ICM-20948	Digital Motion Processor
MPU-9250	Digital Motion Processor

Table 10: Different IMU Chips

Some of the listed IMUs are reaching end-of-life (EOL) and are no longer in production. Others using the integrated Digital Motion Processor (DMP) have difficult documentation. The IMU chosen is the *BNO085* which is built on the same hardware as the BNO055 but with an updated firmware for better performance.

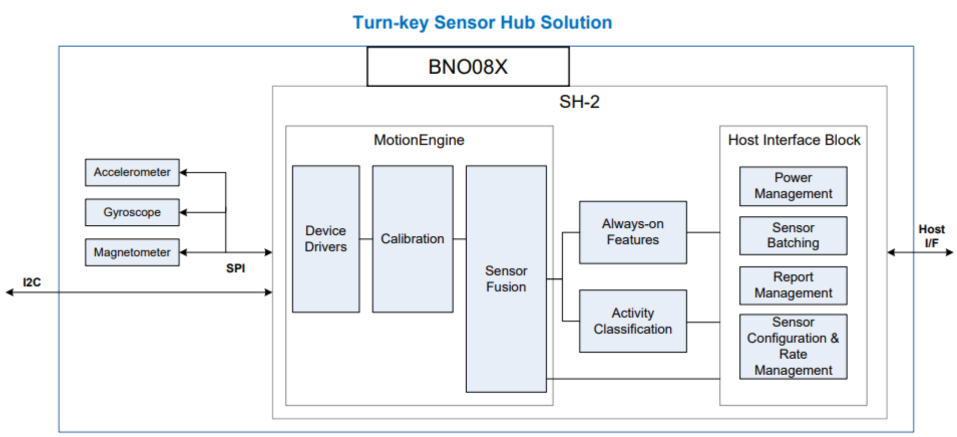

Figure 32: 10 BNO085 block diagram (Copyright pending)

3.4 Bluetooth Selection

When performing a search on Mouser Electronics, many different models of Bluetooth modules come up. As mentioned under the Bluetooth section (2.4) of the technology investigation, the group has opted to use a module with a lower transmit power

(+10 dBm) and one with a built-in antenna. In addition, it is also compatible with the USART serial interface and meets the criteria for our design.

Specifically, the group has chosen the *Silicon Labs 802.15.1 BGM240PA22VNA3R*.

BGM240PA22VNA3R	**Specifications**
Protocol Stack	Bluetooth Low Energy 5.3 Bluetooth Mesh
Max TX Power	+10 dBm
Security	Vault Mid
Antenna	Built-in
Flash (kB)	1536
RAM (kB)	256
GPIO	26
Temp Range	-40 to 105 Celsius
Carrier	Reel

Table 11: Bluetooth Module Specifications

Some of the features of the module are:

- 32-bit ARM® Cortex®-M33 core with 78MHz maximum operating frequency
- 1536kB of flash and 256kB of RAM
- High-performance radio with up to +19.6 dBm output power
- Energy efficient design with low active and sleep currents
- Robust peripheral set and up to 26 GPIO

3.5 Voltage Regulator Selection

As of right now we have not come to a complete decision in the direction in which we want to go with in selecting a voltage regulator. We are still looking into our options in regard to the other components that we are aiming to use in our design.

3.6 Motor Selection

Figure 33: Bafang G310 Motor Schematic (Copyright pending)

Specifications	G310 Motor
Actual weight (kg)	2.55
Power Range (Watts)	250 - 500
Motor KV (RPM/V)	8.5
Phase Resistance (Ohm)	0.124
Disk Brake Compatible	Yes
Connectors	Z910
Thermistor style	10K NTC, B – 3450 with 10K pullup Multiplexed with Speedo
Axle Length	138
Axle Threads	3/8” x 26 tpi
Spoke holes	36 Hole
Motor type	Geared
Flange Spoke Diameter (mm)	123
Magnetic Pole Pairs (Phaserunner)	88
Hysteresis Losses (N-m)	0.666
Eddie Losses (N-m / rad/sec)	0.015
Motor Inductance (H)	0.00021

Table 12: Motor Design Specification

With a lot of the research that was conducted in terms of the motor we came to the decision of choosing a geared rear hub motor. The one in which we are looking at is the *Bafang G310 Standard Wind (8.5 rpm/V) Geared Rear Hub Motor*. The *Bafang G310* motor is a 2.5-kilogram rear hub that is compatible with small disks and has a nominal 250–350-watt power rating. It works well for covert systems that don't need much assistance for steep slopes or heavy loads. In order to use a CA-DP device and avoid the need for an external speedo pickup, this motor has an integrated 6-pole speedometer sensor. It has spiral gears on a second stage planetary gear's first reduction and is remarkably quiet for a geared motor. uses a side cable exit and a cassette freehub mechanism rather than a screw-on freewheel. This hub has a typical RPM/V winding that is appropriate for 26" and 700c wheels. The motors price point before tax is at about $240 USD.

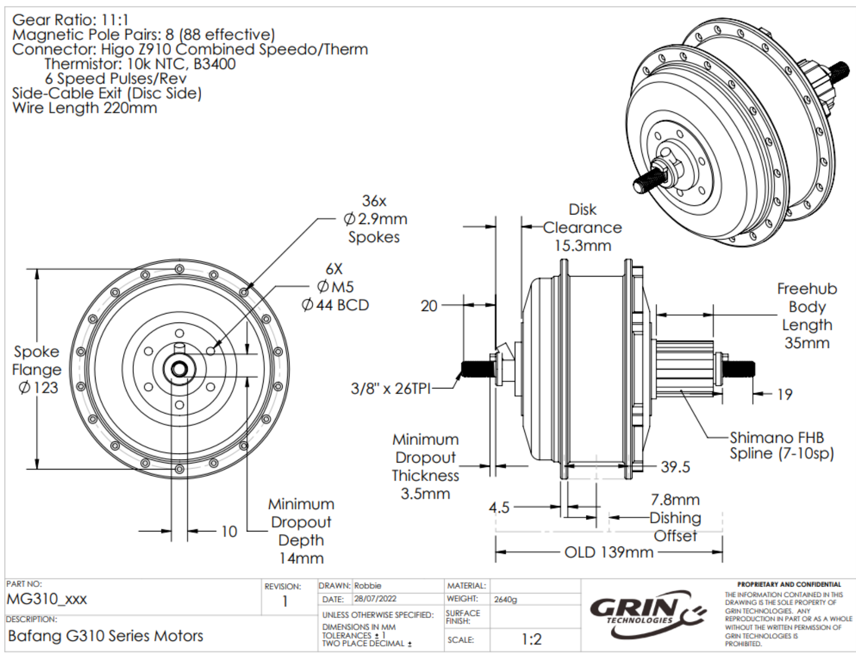

Figure 34: Bafang G310 Motor Schematic (Copyright pending)

3.7 Throttle Selection

For the throttle on the e-bike, the group has decided to go with a twist throttle; the full-twist, specifically. For this selection, the *Keenso Full-Twist* throttle will be used.

3.8 Brake Selection

There are a few different types of brakes we could use, however, we will need to determine what would be the best option for the e-bike we will use based off the requirements we have. The two most common are the rim brakes and the disc brakes. Each has their own positives and negatives that will need to be taken into account when deciding which one to utilize.

The speed of the e-bike will be going fairly fast with a max of 19.5 miles per hour so as not to go beyond the class two e-bike. We can look at automobiles for some inspiration for the type of brakes we should use. Automobiles use disc brakes because of the stronger stopping power over that of other types in the front, however, recent information states that disc brakes are now used on all wheels. This is an option for an e-bike that we could consider because of the added momentum and weight that is added because of all the parts added to the e-bike.

	Rim brake	**Disc brake**
Market availability	High	High
Cost	High	Medium
Heat dissipation	Low to high Depends on size of disc	High
Weight	High	Low
Reliability	High	Medium
Ease of replacement	Low	High

Table 13: Comparing types of Brakes

From the table we can see these differences between the two most common types of brakes along with their positives and negatives. We will need to decide if we want the disc brakes but because of the nature of the project rim and the use case for the bicycle, rim brakes should be fine. They should also allow easier replacement and are cheaper if something does go wrong or brakes while testing or fixing the e-bike.

The rim brake type we would use is a dual-pivot side-pull rim brake. The reason for this is the better braking compared to other rim brake types. Below is an example of that type of rim brake.

Figure 35: Dual pivot side-pull caliper brake

The current choice is *SUNLIGHT Dual Pivot Brake Caliper, 39-49mm Reach*. This is because the cost is low and we will also need to purchase a cable set so it is not too much extra work and would allow us to have a better understanding of how these rim brakes work.

3.9 App Design

When considering many different factors including, but not limited to testing inclusion, learnability, and progress efficiency, the group has decided to use *Flutter* as the UI framework for the smartphone companion app, as well at utilizing a BaaS; specifically, we are choosing *Firebase*. This is to keep the technologies developer-consistent since both Flutter and Firebase are developed and maintained by Google. It can be expected that the documentation and support for both are of good quality/availability.

Although this may lead to being the most expensive solution, it will, no doubt, save the team a lot of time with development.

3.10 Lights Selection

Considering the options available for lighting, LEDs seem to be the most reasonable. Although they do cost a little more than incandescent bulbs, not only are they more reliable and dependent, but they are also much more power efficient. So the group has decided to go with LEDs for lighting on the e-bike.

There are many options of LEDs to choose from, but the group has opted to go with a strip of LEDs; specifically the *Adafruit RGB LED Weatherproof Flexi-strip 1m* strip of

LEDs. This gives us the flexibility to cut and reuse sections of LEDs, with plenty of leeway in case any of the other pieces get damaged/become broken.

4.0 Related Standards and Design Constraints

There are many different governing bodies that regulate in three different ways. These governing bodies can regulate how something is done, i.e. our electrical grid is 240 volts at 60 Hz three-phase. They may require a specific technology to be used, i.e. in Europe recently small electronic connectors are required to be USB-C. The last way is to let the market figure it out which means that the people will vote with their wallets to get what works best for themselves.

In the United States the national standards body is called American National Standards Institute (ANSI). There are however industry standards that communicate with the national body. The one we most commonly hear about is IEEE, which is a Standards Developing Organization (SDO).

In our case the governing body for some parts of the bicycle is governed by ANSI, however, the original standards come from the International Organization for Standardization (ISO). ISO has numerous technical committees labeled ISO/TC "x". The one for cycles is committee 149. They are also the committee responsible for developing the international standards that over 170 countries use.

The cycle safety standards from ISO created International Classification for Standards (ICS) which is a classification of the standard. For example, in our case our division would be 43 which is for road vehicles engineering. Then to further classify, the next number would be 150 for bicycles which would include their components and systems.

The standard is then called ISO "xxxx-x:YYYY" which is underneath the ICS classification. The standard for bicycles is ISO 4210-1:2023, 4210 meaning cycles, the 1 meaning part 1 and 2023 meaning the year the standard was published.

There are other standards such as Underwriters Laboratories Solutions (UL). For this project we won't need to but if we wish to have certification will need to abide by standards set by UL. For e-bikes the certification is UL 2849.

Both UL and ISO create standards for the same thing so a product may have multiple certifications, however, while they may have the certifications the design must comply with the government which all manufactures must comply with.

Design constraints are set by the governmental body of Consumer Product Safety Commission (CPSC). The CPSC put a label on what a bicycle is defined as and different requirements for a bicycle that importers and manufacturers must abide by. For bicycles, including e-bikes, manufacturers must ensure they follow 16 Code of Federal Regulations (CFR) Part 1512.

4.1 Battery Standards/Regulations

There is a difference between standards and regulations in the sense that standards are open to interpretation and may change depending on which regulatory body you go with. Regulations are set by the federal government and must always be followed.

4.1.1 Battery Standards

Current lithium-ion battery standards can be recommended by a few government bodies including CPSC but also United States Agency for International Development (USAID). For CPSC, the staff is currently participating in these standards:

- ANSI/CAN/UL 2272 – Electrical Systems for Personal E-Mobility Devices
- ANSI/NEMA C18 – Safety Standards for Primary, Secondary and Lithium Batteries
- ASTM F2951 – Standard Consumer Safety Specification for Baby Monitors
- ASTM F963 – Standard Consumer Safety Specification for Toy Safety
- IEEE 1625 – Standard for Rechargeable Batteries for Multi-Cell Housing
- IEEE 1725 – Standard for Rechargeable Batteries for Mobile Telephone
- UL 1642 – Standard for Safety for Lithium Batteries
- UL 2054 – Standard for Household and Commercial Batteries
- UL 2056 – Outline of Investigation for Safety of Power Banks
- UL 2595 – Standard for Safety for General Requirements for Battery-Powered Appliances
- UL 4200A – Standard for Safety for Products that Incorporate Button or Coin Cell Batteries Using Lithium Technologies
- UL 60065 – Standard for Audio, Video, and Similar Electronic Apparatus-Safety Requirements

The USAID have a set of standards that should be references as well, some of them are different and will be posted below:

- IEC 61960 – Secondary cells and batteries containing alkaline or other non-acid electrolytes – Secondary lithium cells and batteries for portable applications – Part 3: Prismatic and cylindrical lithium secondary cells and batteries made from them
- IEC 62133-2:2017 – Safety cells and batteries containing alkaline or other electrolytes – Safety requirements for portable sealed secondary lithium cells, and for batteries made from them, for use in portable applications – Part 2: Lithium systems
- IEC 61959:2004 – Secondary cells and batteries containing alkaline or other non-acid electrolytes – Mechanical tests for sealed tests for sealed portable secondary cells and batteries
- UL 9540, 2nd edition – ANSI/CAN/UL Standard for Energy Systems and Equipment
- UL 9540, 4th edition – ANSI/CAN/UL Standard for Test method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
- UL 1973, 2nd edition – ANSI/CAN/UL Standard for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications
- UL 1974, 1st edition – ANSI/CAN/UL Standard for Evaluation for Repurposing Batteries
- JIS C 8715-2 – Secondary Lithium Cells and Batteries for Use in Industrial Applications – Part 2: Tests and requirements of safety

4.1.2 Battery Regulations

Next will be the federal regulations for the transportation of lithium-ion batteries can be viewed in Title 49, subtitle B, chapter 1, subchapter C, part 173, 173.185. These are regulations that apply to nearly all aspects of the battery including: classification, packaging, exceptions, air transportation, batteries sent for disposal or recycling, low production runs and prototypes, damaged batteries, exceptions to air travel and approval.

All the batteries must meet the standard set in the UN Manual of Tests and Criteria. Included in the regulations is what the manufacture must do such as maintain a record of the test report as long as they are transporting it plus one year and need to be available to all forms of government.

There appears to be little no information about how to make the battery and there are minimum safety regulations about how to use batteries and is limited to medical devices. There are also smaller references to batteries across a few different titles in CFR. In title 30, chapter 1, Subchapter O, Part 74, Subchapter C, 74.7 which is about mineral resources there are regulations about the length of time the battery must last (12 hours) and the charger which must operate from a 110 (VAC) (nominal), 60 Hz power line. There is also a reference to if the battery is rechargeable or not. Stating “If the CPDM (Continuous Personal Dust Monitor) uses a rechargeable battery, the CPDM shall have a feature to indicate to the user that the device is sufficiently charges to operate and provide accurate measurements for an entire shift of 12 hours under normal conditions of use".

4.1.3 Motor Regulations

In terms of the motor there are not many regulations regarding it but in many states they are restricted to stay at or under 750 watts.

4.2 Bicycle Standards/Regulations

As stated above the standards for bicycles are maintained by ISO which is what ANSI uses. For the safety of cycles, there are many different parts of the standard. Most are the methods used when testing components.

4.2.1 International Standards for Bicycles

4.2.1.1 Lighting standards

- ISO 6742:2015 – Lighting and retro-reflective devices
- ISO/DIS 6942-1 – Lighting and retro-reflective devices

4.2.1.2 Safety requirements for electrically power assisted cycles.

- ISO 4210 – Safety requirements for bicycles

4.2.2 Federal Regulations for Bicycles

- U.S. Consumer Product Safety Commission's Code of Federal Regulations (CFR), Title 16, Part 1512 – Requirements for Bicycles

4.2.3 State Regulations for Bicycles

- Florida Statutes, Title XXIII, Chapter 316.003 (4) – Bicycle Definition
- Florida Statues, Title XXIII, Chapter 316.2055 – Bicycle Regulations
    - Chapter 316.2055 (7) – Requirements for lighting
- Florida Statues, Title XXIII, Chapter 316.20655 – Electric Bicycle Regulations

Class of Electric Bicycle	State Regulations (Fl)
Class 1	A bicycle with a motor that only assists when the rider is pedaling. Then when reaching approximately 20 miles per hour will stop.
Class 2	A system in which the motor contains a throttle-actuator and stops helping the rider

	once the speed of about 20 miles per hour is met.
Class 3	A bicycle with a motor that only assists when the rider is pedaling. Then when reaching approximately 28 miles per hour will stop.

Table 14: State of Florida Ebike Class Regulations

4.3 Testing Certifications

These are items that require a certification to work with.

4.3.1 ANSI/ESD S20.20-2021: Protection of Electrical and Electronic Parts

According to ESD ADV1.0-2017 electrostatic discharge is “the rapid, spontaneous transfer of electrostatic charge induced by a high electrostatic field. Note: Usually, the charge flows through a spark between two conductive bodies at different electrostatic potentials as they approach one another”.

This certification outlines the development of electrostatic discharge (ESD) programs to protect components that may be sensitive or at risk of damage to ESD. One item that is sensitive to ESD includes microcontrollers, which is something we will be working on for our project. Other items that are sensitive to ESD include integrated circuits and printed circuit boards.

The reason for bringing this up is because the human body is a source of ESD and should be taken into account when working with these sensitive devices, especially when that are not connected to ground. To endure no damage as a result of ESD a device that discharges the body to ground should be used as well as having materials such as rubber matting in working areas to minimize the risk to the above-mentioned components.

4.4 Economic Constraints and Time Constraints

The cost of this system is a constraint that we would like to take into account to ensure that what we do buy, if it breaks we can replace and so if other decide to copy what we do it is cheaper than an average conversion kit that can be bought online. The most expensive components of the bicycle (other than the bike itself which is already owned) will be the battery and the motor. Their higher cost somewhat allows them to stay in stock because less people will want to buy them because of the cost. The global shortage of chips does no appear to still be in effect as of right now but time will tell as we get further into the project if this ends up being a problem.

Time constraints may be a problem with this project, the main battery that is chosen will take only a few days to ship, however, if we go with a much cheaper option that changes to two months to ship. In the end the group will have to decide which one would be preferred. Seeing that the time this project takes will only be a few months as opposed to other project at companies which may take up to a year and a half we must work efficiently and quickly for this project in order to meet the deadline for Senior Design 2. Us getting the components early will allow the group to begin the testing process for the project earlier which lets us figure out any problems and trouble shoot early.

4.5 Environmental and Health Constraints

Currently there is a large push for everything to go electric and to decrease the amount of fossil fuel use. This e-bike will be purely electric and if the user chooses to do so can ignore the motor part of the e-bike and pedal like normal. The highest power draw will be the motor at a maximum of 350 watts but this can be reduced if the stretch goal of assist mode we have planned is implemented. The most damaging component to the environment of the e-bike is most likely the lithium-ion battery pack because of the waste products the come out as a result of the production of the cells.

Safety is also very important to everyone here and we will attempt to follow safety procedures whenever possible. For example following ANSI/ESD S20 and only buying from companies where safety is a high priority such as the battery pack that has a battery management system to help prevent short circuits and to make sure the battery temperature is regulated.

5.0 Project hardware and software design details (Work in progress)

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