3. Design Approach

In this section of the design document, several integral parts of the design process are covered. These topics include the design options under consideration, an overview of the E-Zoom system, and descriptions of each subsystem of the project. The design process is guided by a few key requirements. The E-Zoom consists of fewer than six parts for assembly, enables hybrid e-bike operation by allowing the motor to be disabled or enabled, displays real-time data via an affixed screen, reaches speeds of up to 20 mph in compliance with federal regulations, has a battery life of up to 25 miles, and safeguards the internal electronics against exposure to the elements with an IPX4-level water-resistant design.

3.1. Design Options

The initial design concept for the E-Zoom was to create a full e-bike conversion kit rather than a hybrid conversion kit. Both options have their respective advantages—primarily revolving around their simplicity and flexibility. In the following sections, descriptions of both designs are provided to rationalize and document the shift in design approach.

3.1.1. Design Option 1

Design Option 1 is a full e-bike conversion kit. The kit can convert any bike into an e-bike but takes away the ability to use the bike normally unless the kit is removed from the bike. This design is easier to implement due to it having only a single mode and using the already existing gear. A key drawback is battery management. With no real way to use the bike without a charge, it causes problems for riders who forget to charge their batteries. Overall, the design is easier to implement but significantly reduces the rider's flexibility in terms of riding choices.

3.1.2. Design Option 2

Design Option 2 is a hybrid bike conversion kit. The kit converts any regular bike into a hybrid bike, providing the rider with the flexibility of both electric and manual modes. Unlike Design Option 1, this kit does not present as significant a battery problem because riders have the option to switch back to manual mode when the battery is depleted. This dual functionality ensures that riders can continue to use the bike without the need for a second battery or full charge, making the kit more adaptable to a variety of situations. Implementing this design is more complex, but the design team decided that the flexibility would be incredibly useful.

3.2. System Overview

Fig. 3-1 and Fig 3-2 show the low-level functionality and overview of the E-Zoom kit. Through these diagrams, not only can the relationship between different systems and parts be seen; but also, an image of what the kit might look like when attached to a bike.

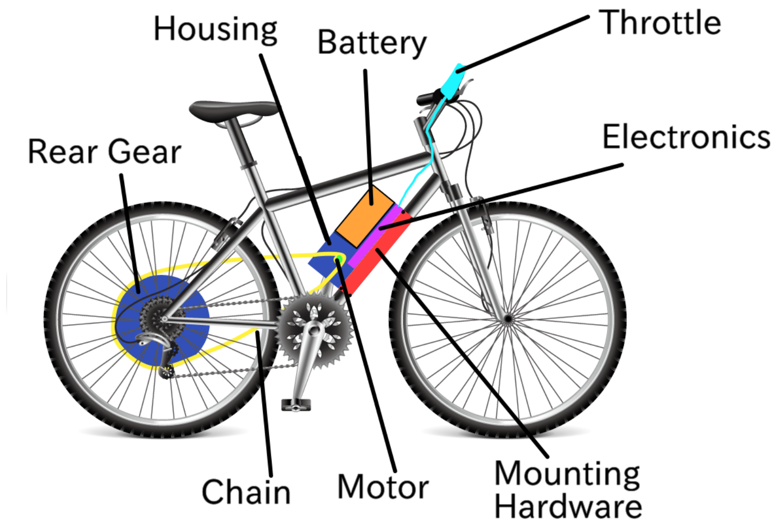

Fig. 3-1: E-Zoom at a Glance (Level 0)

Fig. 3-1 shows how each component attaches to a standard bicycle. The diagram is color coded to represent the different parts and systems.

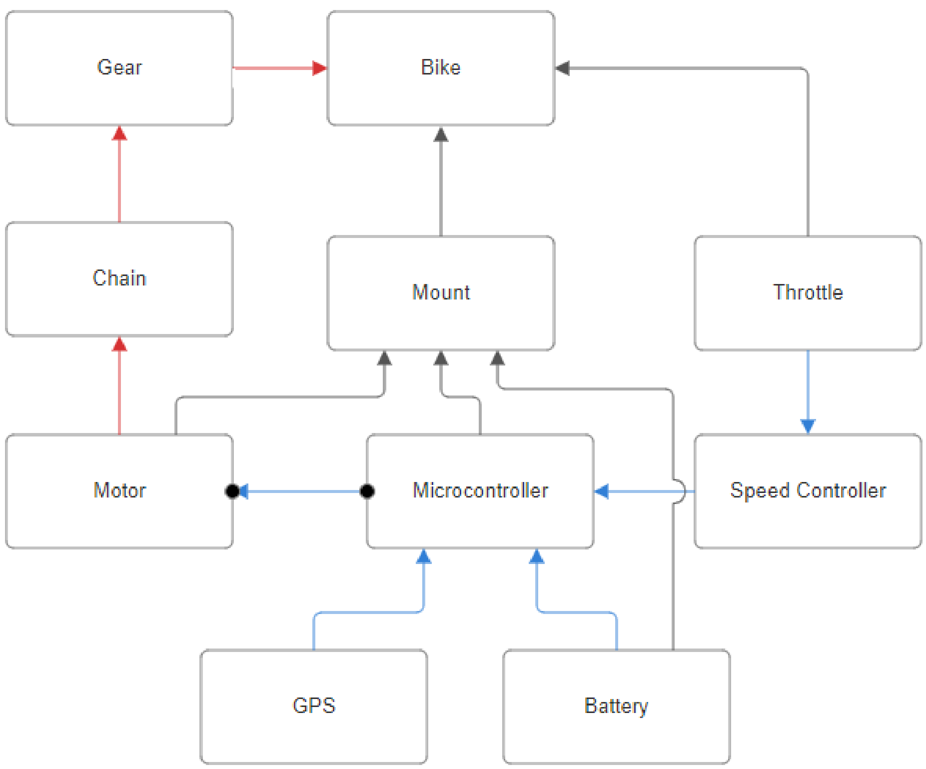

Fig. 3-2: E-Zoom Functionality (Level 1)

Fig. 3-2 shows a diagram of the functionality of the kit and how each system and component sends input, receives output, and mounts to one another. Blue lines are electronic connections. Red lines are mechanical connections. Black lines are physically mounted components.

3.2.1. Microcontroller

The microcontroller for the E-Zoom is an Arduino Uno. Table 3-1 provides more information on controller specifications.

Table 3-1: Microcontroller Options

Product	Cost	Inputs	Outputs
Requirements	<$50	2 analog	3 digital
Arduino Uno [1]	$28	14 digital + 6 analog	14 digital

The Arduino Uno is an affordable microcontroller board costing only $28. It comes with 14 digital input/output ports and 6 analog input ports. For the E-Zoom system, 4 components will be connected to the Arduino at most: the regulator, GPS module, LCD module, and possibly the drive signal wire or speed controller signal wire. With the number of input and output options, the Arduino can drive all systems easily. It is also a very compact board that can fit in a small enclosure. The Arduino ecosystem is also extremely well documented, which helps the design team with debugging and testing.

3.3. Subsystems

The prototype for the E-Zoom electric bicycle conversion kit includes 5 subsystems. Subsystem 1 includes the drive and motor system. This is the subsystem that is directly responsible for the control of the motor and the speed output of the bicycle. Subsystem 2 includes the gear and chain mechanism. This is the system that is responsible for converting the torque and power output of the motor into movement for the bicycle. Subsystem 3 is the central electronics. These are the main hardware components that will interface with the battery, the motor, and all other electronic components. Subsystem 4 is software control and display Interface for the kit. The software for this subsystem is responsible for real-time data processing, user interface design, and interaction with the Arduin microcontroller to display on the LCD screen. Subsystem 5 is the mounting system. This includes all parts that are used to apply the device safely and securely to the bicycle while also ensuring that the device can operate in all reasonable weather conditions.

3.3.1. Motor and Drive System

The motor and drive system includes the motor that drives the bicycle as well as the throttle that allows the user to control the speed and power output of the motor. The motor that is chosen needs to satisfy the capability requirements of being battery powered, have enough power output to move the bicycle at efficient speeds, and be able to run for suitable durations of time. While the throttle that is chosen must be able to interface with the same battery as the motor to modify the motor's output and subsequently change the speed of the bicycle.

The practical solution for the motor is to choose a DC motor that can output sufficient torque and be powered by a rechargeable lithium-ion battery. The throttle should be electronic and able to interface with electric components, thus, making a traditional motorbike/ATV throttle a practical solution as well.

For these we chose to use a 24-volt DC motor with 1000 RPM and high torque capability. This is vital to ensure that the bicycle can run well with people of different weight sizes, and we also chose to use a WPHMOTO brand universal and electronic twist grip throttle that is rated to handle voltages in the range of 12v-84v. Making these the optimal choices for our design needs. Listed in table 3-2 are the possible motor options.

Table 3-2: Motor Options

Product	Voltage	RPM	Cost
Requirements	Able to be powered by a 24-volt battery	Enough to consistently rotate the gears	$10-100
Geartisian DC motor [2]	24v	1000	$14.99
Walfront DC motor	12v	2000	$13.99
Hilitand DC motor	36v	300	$38.85

Fig. 3-3: Geartisian DC Motor

The Geartision DC motor (shown in figure 3-3) has a good balance of power consumption to output. This motor also has a reasonable price range that allows for better value overall while still fitting the necessary criteria.

Table 3-3: Throttle Options

Product	Voltage	Connections	Cost
Requirements	Able to handle 24 volts	Must come with a speed controller to handle the battery and motor interface with the microcontroller	$10-$40
NBPOWER Throttle [3]	24v	No speed controller	$9

Bnineteenteam Throttle	24-36v	Has a speed controller	$92
WPHMOTO Throttle	24v	Has a speed controller	$27

By analyzing our available options in table 3-3 we are able to see that the WHPMOTO comes with the ability to handle the necessary voltages as well as the necessary speed controller that will allow it to properly interface with all other components.

3.3.2. Gear and Chain Mechanism

The gear and chain mechanism interfaces directly between the electronics of the E-Zoom kit and the original hardware of the bike. As a team, many decisions had to be made regarding the gear and chain mechanism. Cost is a key question to answer. Other concerns are weight and durability of both the gears and chain. Three initial options come to mind as to what materials best suit the needs of the kit. The first option is to buy premade gears that fit our project. This option gives us the easiest use of implementation. While giving us the easiest use in testing and offers a pleasant end user experience, the solution is the heaviest and least customizable. To offset those shortcomings, it is also the most durable option available. The second option is to 3D print gears. This option gives some of the most customization we can achieve in designing the components for the kit, but it also has serious drawbacks. One of those concerns is durability. Some plastics used would not be strong enough to withstand the torque of the motor. They would also run the risk of wearing down quickly. The third option is to mill our own custom-made gears. This option is the middle ground between the two mentioned previously. It provides some of the customization that 3D printed parts have, as well as the durability of a premanufactured gear. Some drawbacks of this method are the amount of time it takes to design and mill, and that it is more expensive to implement. With these factors in mind, a premanufactured gear is the option we have chosen for the first iteration of this kit. This is the cheapest and fastest method to complete our kit. At a later point, we would like to design our own gears for the kit. As it stands, the option we picked is the most economical for us as well as the consumer. By using a standard size and manufactured gear, the end user can easily replace and customize their own kit to any other gear that they would like to use.

Table 3-4: Gear Options

Gear	Material	Cost	Description
Requirements	The material should be durable enough to withstand high torque and wear	$20 - $50	The gear must be durable and sturdy while staying within cost and time restrictions.
CDHPOWER 40 Tooth Bike Sprocket [4]	Aluminum	$21.99	This gear is the most accessible option. It is sturdy and durable. The gear is very affordable and is easily replaceable.
3D Printed	Polylactic Acid	$30+	The printed gear is the most customizable option. The gear is

			moderately priced but lacks overall durability.
Machined	Aluminum	$50+	The machined gear is custom made. It is sturdy and durable. Although it would provide the best experience, it is the most expensive option and cannot arrive in time.

Table 3-4 gives a visual reference as to why the specific gear was chosen. The CDHPOWER gear is very affordable and made with durable enough materials for the project. The option that the team had also considered heavily was the machined gear. It gives more customization in the design of the gears, but the gear would not be machined and arrive in time.

The other major decision to be made with the gear and chain mechanism is whether to use a chain explicitly or in conjunction with plastic pulleys and rubber treads. This debate was settled rather quickly. Plastic pulleys frequently skip under high torque and potentially melt under high heat. These critical flaws disqualify pulleys from being used in the kit. The only logical option was to use a standard bike chain. A standard bike chain also allows for the system to be easily repaired and modified without the need for proprietary parts.

3.3.3. Central Electronics

The central electronics are required to drive the LCD with data from the battery and the GPS module. All logic is driven using an Arduino Uno. The Arduino has the ability to interface with multiple analog and digital inputs, is already in the possession of most team members, and is familiar to team members.
For measuring the speed, a variety of options were considered. Since an Arduino Uno is used for the central logic, the speed tracking hardware options are all compatible Arduino modules. Due to an IR sensor needing to be attached to the bike's wheel, the GPS module was chosen instead. Placing a sensor on the wheel makes it susceptible to the elements and constant rough motion, which increases the chances of mechanical failure. The GPS module can be positioned inside of or on the side of the housing, which decreases the number of separate parts and keeps it protected. It also has built-in functions that allow for the collection of accurate speed data using its positional data that are well documented and easy to use. Listed in Table 3-4 are possible speed tracking options.

Table 3-5: Speed Tracking Options

Product	Tracking Method	Cost
Requirements	Measures speed using the Arduino Uno. Attaches to a secure and feasible section of the bike.	<$15
DAOKI IR Sensor Module [5]	Uses an infrared sensor to detect objects in front of it. By placing the sensor on a wheel, the speed	$1.16

	traveled can be calculated using the size of the wheel and the number of full rotations. The sensor can be triggered using the bars that attach the wheel to the bike.	
HiLetgo GY-NEO6MV2 NEO-6M GPS Module [6]	Uses a satellite connection to receive positional data.	$8.99
DAOKI LM393 Speed Measuring Module [7]	Uses a coupler circuit to measure speed of an object that passes between 2 sensors.	$1.56

To power the Arduino, a voltage regulator is necessary between the Arduino and the battery because the Arduino only accepts a voltage power input between 5V and 12V. The regulator must convert 24V or more down to 5 - 12V. Due to the 5V power input the Arduino can only output around 4.25V when powered by the battery. This is not an issue because the other components powered by the Arduino can operate between 3V and 5V. The UCTRONICS U6223 was chosen by the design team due to its ability to convert 24V to 5V and its affordable price. Listed in Table 3-6 are the voltage regulator options.

Table 3-6: Voltage Regulator Options

Product	Regulator Voltages	Cost
Requirements	24V+ regulated down to 5V	<$15
DROK LM2596 [8]	4-32v down to 1.25-30V	$12.99
UCTRONICS U6223 [9]	9-24V down to 5V	$7.50
EKYLIN Step-Down Converter [10]	12-24V down to 5V	$12.00

To display battery metrics, a voltage divider circuit is constructed in order to reduce the 24V battery's output down to under 5V. As seen in (1), with 24V being the input and 5V being the output, 3.9k and 1k resistors are used for the divider. The battery voltage varies as it depletes, and since the output voltage is directly linked to the input voltage, the measured voltage is expected to decline proportionally as the battery drains. This allows for the measured voltage to be checked and compared against the fully charged and fully depleted values, which gives a percentage indicator of battery life. This information will help users manage their devices effectively and prevent unexpected power interruptions.

$$Vout = Vin * (R2)/(R1 + R2) \tag{1}$$

For the display, a standard OLED module is used. Alternatively, an LCD module can be used, but due to the LCD being difficult to see in sunlight and only allowing for 32 characters the OLED is preferred. Both options are only rated for 5V which is within specification for the Arduino Uno. Unless any roadblock arises as a consequence of its use, the standard OLED is sufficient. Listed in Table 3-6 are the display options.

Table 3-7: Display Options

Product	Operating Voltage	Display Resolution	Cost

Requirements	5V	Display at least 20 characters	< $10
Hosyond OLED I2C Display Module [11]	3.3 - 5V	128x64 Pixels	$3
GeeekPi 1602 LCD Display Module [12]	5V	16x2 Characters	$5

These components will allow the central electronics subsystem to display both battery and speed metrics to the rider.

3.3.4. Software

The Software Control and Display Interface are developed using C++ for optimal performance with the Arduino. It collects and processes real-time data and is displayed through the LCD screen. Riders are presented with a clear view of battery life and travel speed. One of the main reasons for choosing C++ is because of its performance capabilities. It is also beginner friendly and there are a lot of resources online to help if any problems arise. It also offers a blend of high-level and low-level features. This balance is essential for our power management and memory efficiency.

3.3.5. Mounting System

The mounting system incorporates a housing box designed to accommodate all the electronics, including the battery, motor, and Arduino components. This housing box undergoes fabrication through 3D printing for the prototype. The dimensions of this housing box measure 12.8 inches in length, 4 inches in width, and 3.5 inches in height. To ensure stability, it is firmly secured with four bolts, and a dedicated base provides additional support and security for the electronics box. Additionally, the design incorporates features to enhance its resistance to dust and splashes.

3.4. Level 2 Prototype Design

The next step for the E-Zoom bike is to enhance its usability and user experience. This will mainly be focusing on the software aspects, unless the hardware causes some changes in the physical aspects of the mounting device. At this stage, certain components might be replaced or refined based on testing and feedback. Here are some examples that could be added after all the necessary requirements are met. For example, a digital clock, battery-run mileage estimation, energy recovery system, environmental sensor integration, adaptive lighting for the LCD screen, and the main one would be a functional app that any user can download from any device.

3.4.1. Level 2 Diagram

Below, Fig. 3-4 shows the level 2 diagram of the E-Zoom kit. As testing and trial happens, some parts may differ and change. This diagram illustrates the planned materials used and implemented in the E-Zoom conversion kit.

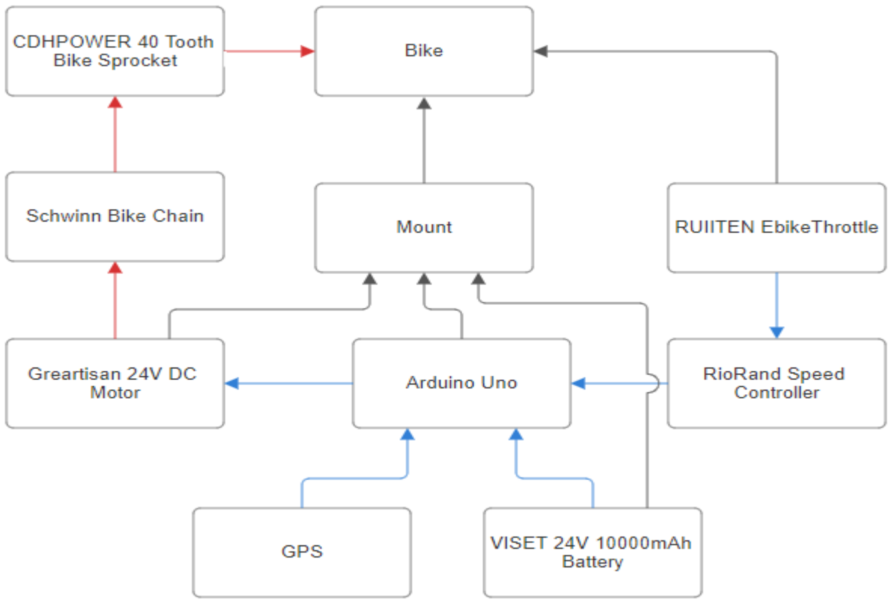

Fig. 3-4: Diagram for E-Zoom Kit (Level 2)

As can be seen in Fig. 3-4, the design of the E-Zoom kit has been thought through thoroughly. By using an Arduino Uno to drive the electronics, the branching components can be easily maintained and implemented. Attached from there is the battery, GPS module, speed controller, and motor. The input received from the GPS module is used to calculate the speed of the bike. The VISET Battery provides the power to drive the kit. Connected to the bike's handlebars is the RUIITEN Ebike throttle which acts as a potentiometer that inputs into the RioRand speed controller to control the speed of the motor. That signal from the speed controller is sent into the Arduino Uno and out into the Greartisan 24V motor. This is the component that drives the gear and chain mechanism to power the bike. The motor, Arduino, and battery are housed in the mount on the bike. The chain attaches from the motor to the CDHPOWER gear on the rear wheel of the bike.

The E-Zoom kit has many components that are integral to its performance. These are divided into subsystems that have been thoroughly detailed throughout this section. In the following document, the testing of the subsystems is documented.

3.4.2. References

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