ECE 445 - Fall 2025

Senior Design Project Proposal

E-Bike Crash Detection and Safety

Team 6

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Table Of Contents:

1. Introduction

1.1 Problem and Solution

E-bikes are rapidly becoming one of the most popular forms of personal electric transportation due to their low environmental impact, affordability, and accessibility. However, the increase in e-bike adoption has been leading to a growing number of crash-related injuries. A unique hazard arises when the electric motor continues to operate after a crash, propelling the bike forward while the rider may be incapacitated or separated from the frame. Current consumer e-bikes typically rely on manual shutdown or smartphone-based emergency alerts, both of which respond only after an accident has already occurred. None of these solutions directly address the moment of impact or the immediate danger of an active motor.

To address this issue, our project introduces an E-Bike Crash Detection and Automatic Motor Cutoff System. The device combines inertial sensors such as an accelerometer and gyroscope, along with motor feedback, to detect crash conditions in real time. When a crash or rollover is identified, the system instantly disables motor output by signaling a safety cutoff circuit integrated into the motor controller. A manual reset switch allows the rider to restore functionality after confirming safety. This design emphasizes immediate response within 10–20 ms, multi-sensor verification to prevent false triggers, and modular hardware for integration into different e-bike systems.

1.2 Visual Aid

Figure 1 shows the conceptual overview of our E-Bike Crash Detection and Safety System in operation. The device is mounted on the front of an e-bike and continuously monitors acceleration and angular velocity through an onboard accelerometer and gyroscope. During normal riding, these sensors feed real-time motion data to the ESP32 microcontroller, which determines whether the detected motion exceeds preset crash or tilt thresholds. If a sudden impact or rollover is detected, the microcontroller triggers a cutoff signal that immediately disables power to the e-bike motor. For demonstration purposes, the system's functionality will be verified using a smaller 5V DC motor to simulate motor response. The goal of this design is to ensure that in a real crash scenario, the e-bike motor is safely shut off within milliseconds, preventing further motion or injury to the rider.

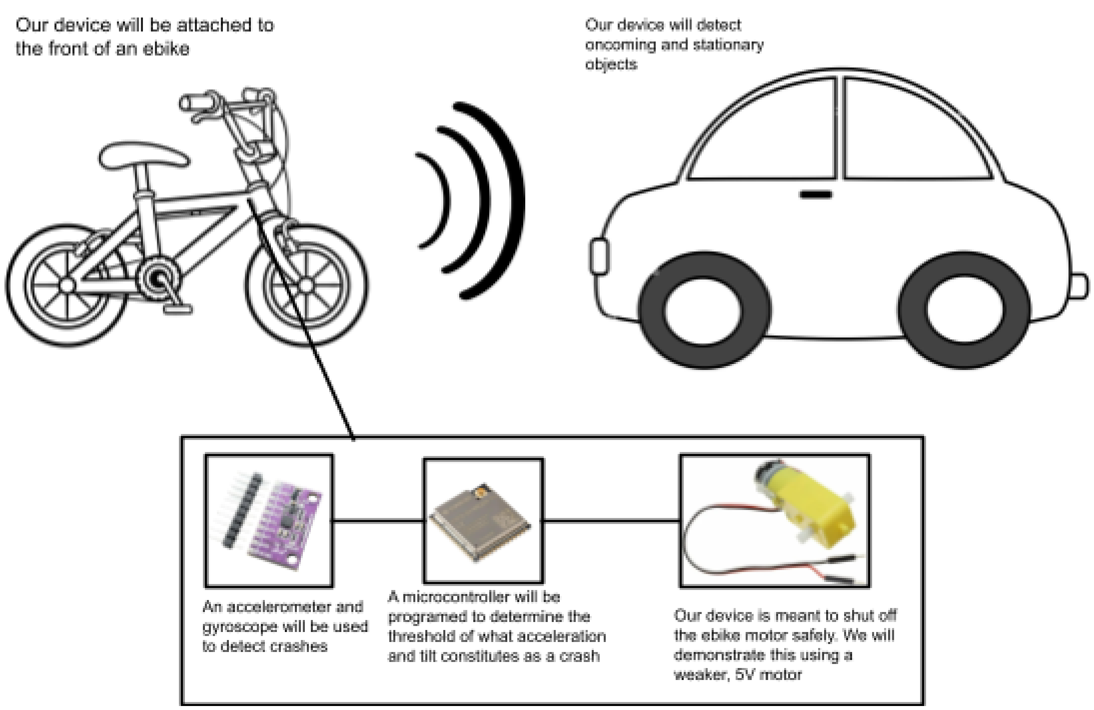

Figure 1: Visual Aid

1.3 High Level Requirements

Motor Impact Cutoff: The system must detect a head-on collision from rapid changes in acceleration and disable motor power within 10-20 ms to prevent the bike from moving forward after impact.

- Flip/Rollover Cutoff: The system must detect a rollover or tip-over event by monitoring tilt and angular velocity and disable motor power within 20 ms to stop wheel movement while the bike is on its side.
- Reset Functionality: A manual reset switch must allow the rider to clear the cutoff signal and restore motor power after a crash or false trigger, ensuring safe continuation without restarting the device.
- The system must be able to allow a throttle to change the speed of the motor when no crash has been detected and disable the throttle signal after a crash has been detected.

2. Design

2.1 Block Design

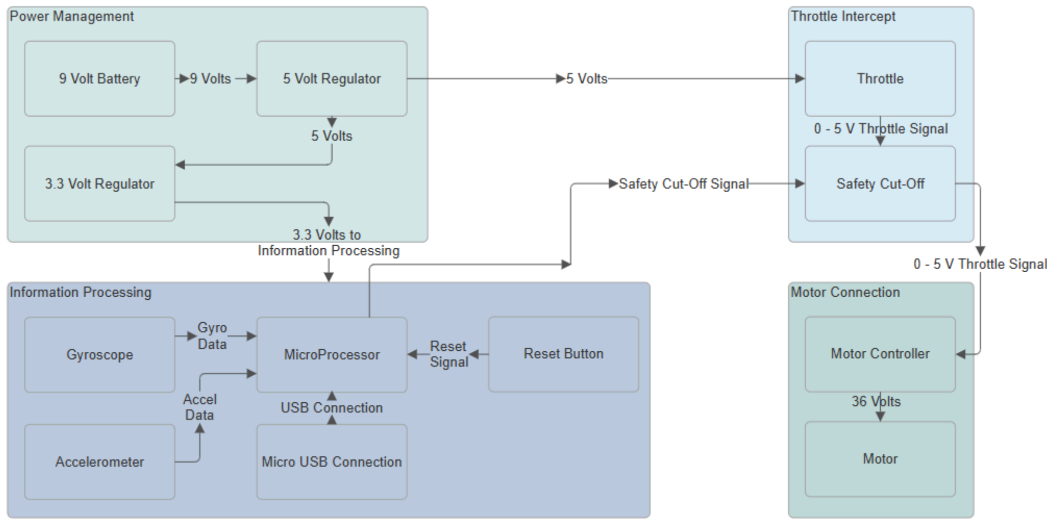

Figure 2: Subsystem Block Diagram

Figure 2 shows how each subsystem in our E-Bike Crash Detection and Automatic Motor Cutoff System interacts. The power management subsystem is required to power our entire system. We will have a 9 volt battery, supplying a voltage to a 5 volt and 3.3 volt regulator to safely provide power to the rest of our components. The Information subsystem will contain our microprocessor, reset button, USB connection to the microprocessor, gyroscope and our accelerometer. The gyroscope and accelerometer will be used to send data to our microprocessor The Throttle Intercept subsystem will contain the throttle and the circuit responsible for intercepting the throttle signal to turn off the motor. Our final subsystem is in the Motor Operation subsystem. This subsystem will contain the motor controller, which steps up the power from the throttle to match the motor’s requirements to operate. In our demonstration, we will use a smaller signal level motor to illustrate our systems ability to disable motor control when a crash is detected.

2.2 Physical Design

All the components for our crash detection system will be mounted primarily under the bike seat and on the handlebars, where the throttle is located. The ESP32-S3 microcontroller, power regulation circuit, and IMU sensor (ICM-20948) will be secured under the seat in small protective cases to shield them from vibration, dust, and moisture. The reset button and indicator LEDs will be mounted on the handlebars next to the throttle, allowing the rider to easily access and monitor them while riding. Wiring will be neatly routed along the bike frame to connect the under-seat electronics to the handlebar controls and the motor shutoff output. This layout ensures the system remains compact, durable, and convenient for operation and maintenance during testing and normal use.

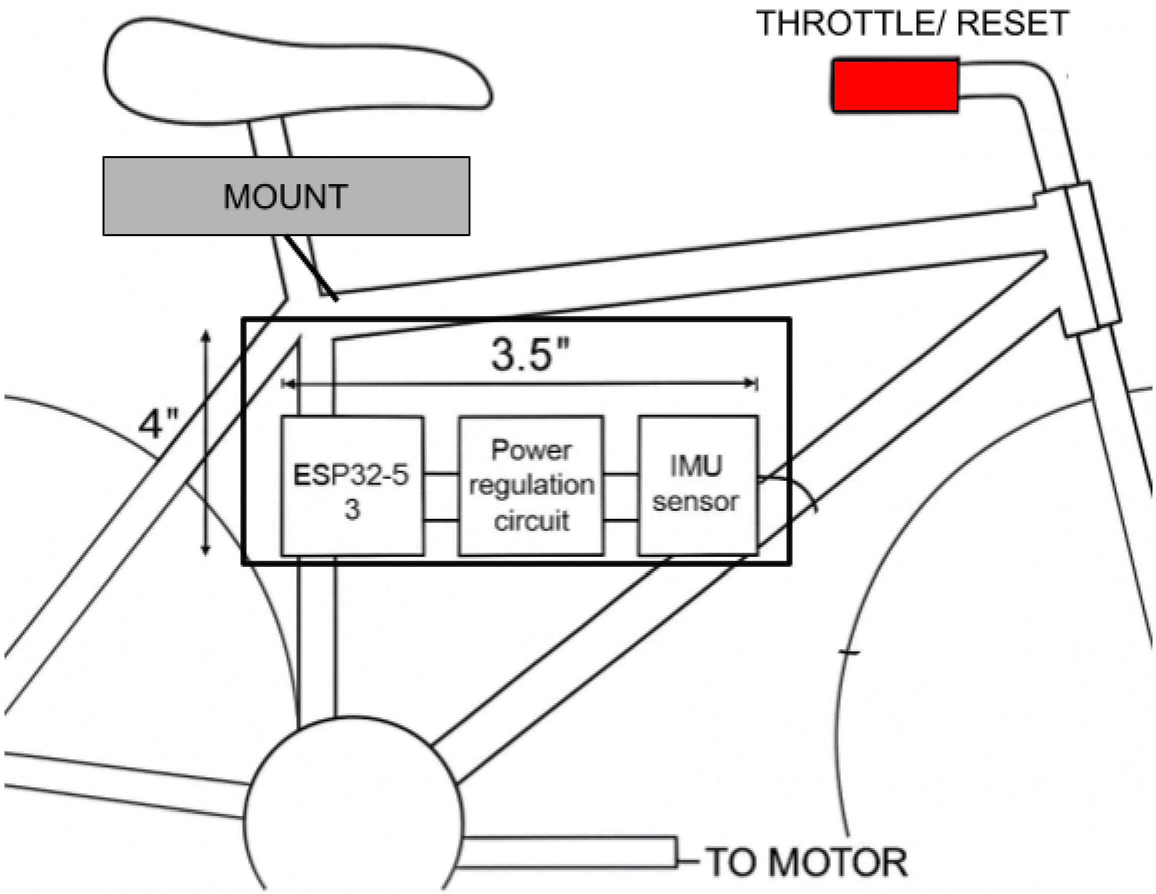

Figure 3: Physical Design Diagram

2.3. Subsystem Overview & Requirements

2.3.1 Power Management

The power management subsystem will be used to power all of our other subsystems. We will be using a 9 volt battery to provide power to our E-Bike Crash Detection and Automatic Motor Cutoff System. As seen in figure 4, this 9 volt power supply will send 9 volts to a 5 volt regulator. This regulator will safely convert the 9 volts into 5 volts. The 5 volts will then be sent to the 3.3 volt regular and the throttle. The 3.3 volt regulator within the power management subsystem, takes the 5 volts from the 5 volt regulator, and steps it down to 3.3 volts. This 3.3

volts goes to every component in our Information Processing system.

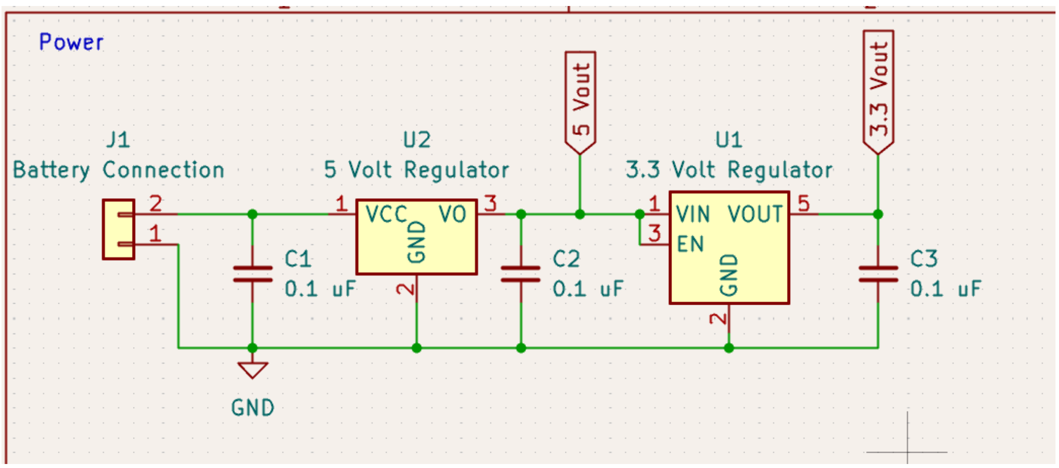

Figure 4: Power Management Subsystem

Table 1: Requirements and Verifications of the Power Management Subsystem

The 5 Volt regulator should be able to step down the voltage of the 9 volt power supply to 5 volts.	• Test point before the 5 volt regulator to see input voltage. • Test point after the 5 volt regulator to determine the output voltage.
The 3.3 Volt regulator should be able to step down 5 volts from the 5 volt regulator to 3.3 volts.	• Test point after the 3.3 volt regulator to ensure correct output voltage. • Prove components of the Information Processing subsystem to ensure secure connections between components and the 3.3 volt regulator.

2.3.2 Information Processing

The Information Processing subsystem is responsible for gathering data during a bike ride, and detecting if there is a crash. Each component in this subsystem is powered by the 3.3 volts sent from the 3.3 volt regulator. We are using a gyroscope and accelerometer to gather data and detect a crash. For this, we are using a ICM 20948 chip. We will send this data to our micro-processor. To upload software into our microprocessor, we will be using a micro-usb connection as seen in figure 5. In addition, we added a reset button that when pressed, sends a 3.3 volt signal to the micro processor which will reset the safety signal.

The microprocessor in this subsystem is responsible for interpreting the data from the gyroscope and accelerometer. Its job is to take the information from our sensors and determine if there is a crash. If a crash is detected, it will send a 3.3 volt signal to the safety cut-off circuit in the throttle intercept subsystem.

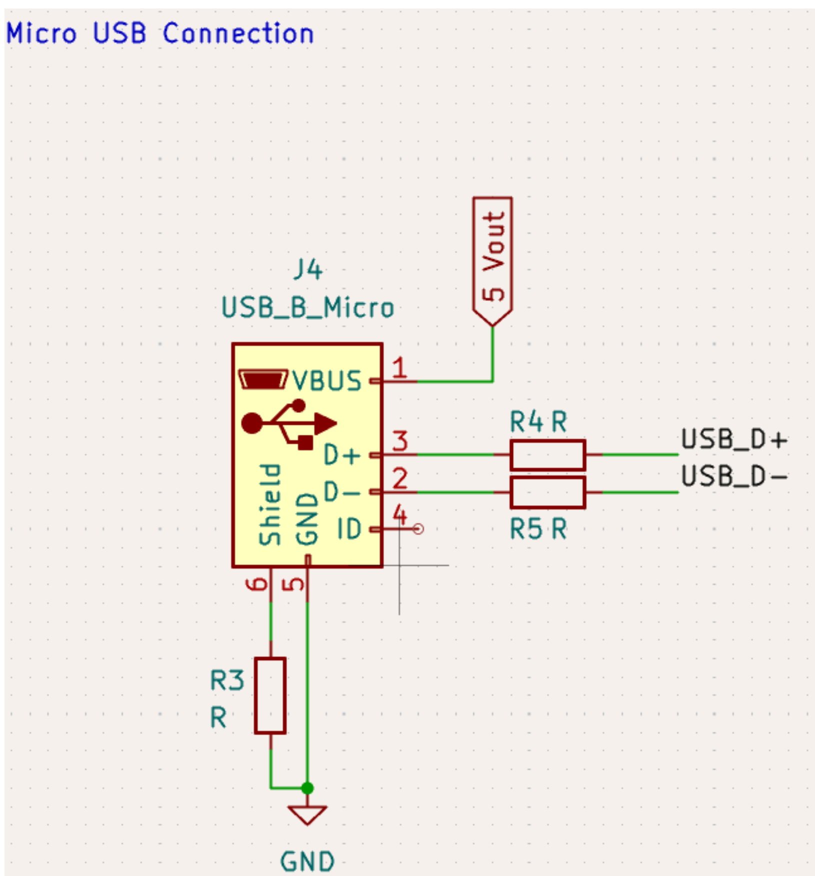

Figure 5: USB Connection Circuit

Table 2: Requirements and Verifications of the Information Processing Subsystem

An accelerometer must accurately measure linear acceleration in the X, Y, and Z planes within +/- 0.05g	● After connecting the accelerometer to the microprocessor, confirm communication using Arduino IDE serial monitor. ● Apply a controlled acceleration to each direction, to confirm accuracy of motion capture.
The gyroscope must accurately measure angular velocity in the X, Y, and Z planes within +/- 0.05% accuracy	● After connecting the gyroscope to the microprocessor, tilt the gyroscope at a controlled speed to test accuracy. ● Verify communication between the gyroscope and the microprocessor using the Arduino IDE serial monitor.
The microprocessor needs to be able to read gyroscope and accelerometer data. A microprocessor should send a 3.3 volt signal to the safety cut-off circuit when a crash has been detected. The reset button should restart the program in the microprocessor.	● Check the Arduino serial monitor to see if there is serial communication with the accelerometer and gyroscope. ● Applying different tilt speeds and linear acceleration to determine microprocessors can accurately read data. ● Use a test point at the base of NPN Q2 to check the voltage of safety cut-off signal ● Use a test point at the base of NPN Q2 to check the voltage of the safety cut-off signal and make sure it is low.
The micro usb must enable software and firmware upload to the microprocessor.	● Connect the device to a PC using micro-USB and confirm COM port detection. ● Successfully upload firmware using Arduino App.
The reset button must reset the microcontroller and restart the program when	● Press the reset button and confirm that the microprocessor resets.

pressed.	• Visibly check if the motor is able to work again, after button press.

2.3.3 Throttle Intercept

The Throttle Intercept subsystem is made up of the throttle and safety cut-off circuit. The throttle receives 5 volts from the 5 volt regulator and depending on how far turned, it will send a variable voltage (from 0 to 5 volts) to the safety cut-off circuit.

The safety cut-off circuit seen in figure 6, uses npn BJTs to safely intercept the signal from the throttle before it goes to the motor controller. When this circuit receives a 3.3 volt signal from the microcontroller, the voltage through the motor controller will be weakened enough so that the voltage across it is under the motor controller's threshold voltage, disabling the motor.

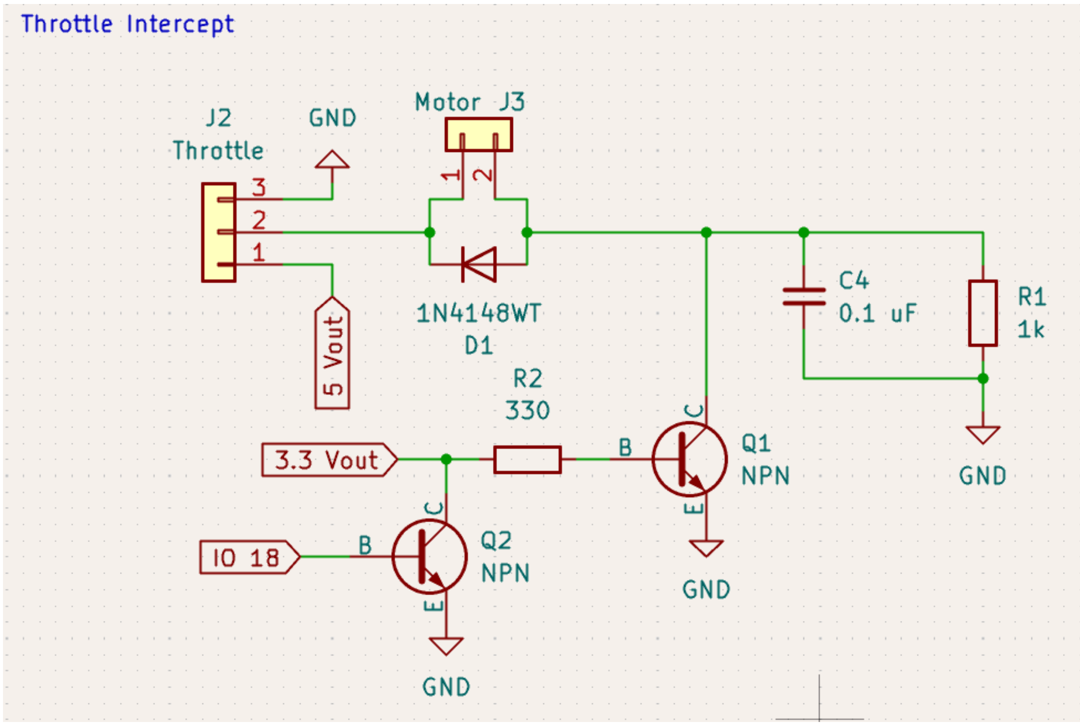

Figure 5: Safety Cut-Off Circuit

Table 3: Requirements and Verifications of the Throttle Intercept Subsystem

When the safety cut-off signal is low, the motor controller should see all of the voltage provided by the throttle.	• Probe the current across the collector and emitter of NPN Q1 to see if all of the current from the motor goes across to ground. • Probe current across the collector and emitter of NPN Q2 to see if 0 current flows across the BJT.
When the safety signal is high, the voltage across the motor should decrease below the motor controller's threshold voltage.	• Test point across the motor to see if the voltage is under 2 volts. • Test point on the base of NPN Q2 to see if the safety signal is present. • Test point across the base of NPN Q1 to see if the BJT is turned off.

2.3.4 Motor Connection

The motor connection subsystem houses the motor and motor controller. The motor controller is connected to the safety cut-off circuit and receives the voltage from the throttle as long as the safety cut-off signal is low. The motor controller then steps up the voltage of the throttle signal using the main battery of the e-bike to the rated voltage of the motor. The motor in this subsystem is the motor that is attached to the e-bike.

In our demonstration, the motor connection will be a signal level motor. This signal level motor can operate on a lower voltage like the 0 to 5 volt voltage from the throttle, and accurately depict how a motor controller would react to the E-Bike Crash Detection and Automatic Motor Cutoff System.

Table 4: Requirements and Verifications of the Motor Connection Subsystem

The motor controller should not step up throttle voltage when the safety cut-off signal is high.	● Probe across the motor controllers terminal to check if the voltage is beneath its threshold turn on voltage. ● Test point before the motor to see if the motor is receiving a voltage.
The motor controller should step up the 0 to 5 volt throttle signal when the safety cut-off signal is low.	● Probe across the motor controllers terminal to check if the voltage is above its threshold turn on voltage. ● Test point before the motor to see if the motor is receiving a voltage. ● Visibly check to see if the motor is spinning.

2.4. Tolerance Analysis:

A critical parameter in our design is the reaction time of the crash detection system. The motor must cut off within 20 ms of a collision event to prevent the rider from being dragged by the bike. If this timing extends much beyond 20 ms, the rider risks being pulled forward or losing control. If it is too fast or too sensitive, the system could trigger false positives during normal vibrations or bumps. To manage this, we set thresholds such that linear acceleration above approximately 80 m/s^2 or angular velocity above 300 degrees/s reliably indicates a crash condition while maintaining less than 5% false triggers.

The total response time of the system depends on several subsystems working together. The IMU samples data at 1 kHz, providing new readings every 1 ms. The microcontroller executes the crash detection algorithm and outputs a cutoff signal within 0.2 ms, and the L298N cutoff driver disables the motor circuit in less than 0.05 ms. The motor current then decays to zero within approximately 0.3 ms. Even under worst-case tolerances, the total cutoff reaction time remains below 4 ms, which is well within our 20 ms requirement and ensures fast and reliable motor shutdown.

The power subsystem also has strict tolerance requirements. The microcontroller and IMU require 3.3 V ± 5 %, while the cutoff driver requires 5 V ± 5 %. Any voltage droop outside these ranges could cause delayed response or missed detections. Our voltage regulators are designed for at least 80 % efficiency to minimize heat and maintain stable operation under load.

Calculation Example:

At a wheel radius of 0.35 m and a cutoff delay of 0.02 s, a bike traveling at 5 m/s (≈ 18 km/h) will move:

Distance = velocity × delay = 5 m/s × 0.02 s = 0.1 m

This means the rider would be carried forward only 10 cm before the motor shuts off. Any delay beyond this would significantly increase risk, making our 20 ms tolerance essential for safety.

3. Cost and Schedule:

3.1. Cost Analysis:

3.1.1 Labor:

For our labor estimation we believe each team member will have worked approximately 120 hours over the course of the semester. Assuming a reasonable salary for an ECE graduate is around $40/hour, we say the total labor cost for one person is:

($40 /hour × 2.5 × 120 hours) = $12,000 per person.

With three team members, the total estimated labor cost is:

3 × $12,000 = $36,000 total labor cost.

3.1.2 Parts and Materials

The project uses a compact set of components: an ESP32-S3 microcontroller, ICM-42688 6-DoF IMU, 3-axis magnetometer, AP2112K-3.3 voltage regulator, a toggle switch, push buttons, LED indicators with resistors, a 5 V DC motor (for demonstration), and a custom PCB. Minor consumables such as connectors, wiring, and headers are also included.

Parts List:

Description	Manufacturer / Part #	Qty	Unit Cost (USD)	Total Cost (USD)
ESP32-S3 microcontroller module	Espressif ESP32-S3-WROOM-1-N8R2	1	8.50	8.50
6-DoF IMU (accelerometer + gyroscope)	TDK InvenSense ICM-42688-P	1	4.00	4.00
3-axis magnetometer	ST Microelectronics LSM303AGR	1	3.00	3.00
3.3 V regulator	Diodes Inc. AP2112K-3.3TRG1	1	0.75	0.75
Reset / cutoff switch	Generic SPST toggle switch	1	3.00	3.00
Push buttons (for reset / test)	Generic tactile button 6 mm	2	0.25	0.50
Indicator LEDs + resistors	Generic pack	1 lot	1.00	1.00
Prototype motor (5 V DC)	Generic DC motor	1	6.00	6.00
Custom PCB (2-layer ≤ 10×10 cm)	JLCPCB / PCBWay	1 lot	25.00	25.00
Connectors / headers / wire / heat-shrink	Generic kit	1 lot	10.00	10.00
Estimated Parts Total				$61.75
Shipping + contingency (~15 %)				$9.25
Parts & Materials Total				$71.00

The total expected cost of parts including shipping is approximately $70–$80.

Services and Fabrication

Custom PCB fabrication cost around $20–$40 depending on supplier and quantity.

3.1.3 Total Estimated Project Cost

Labor: $36,000

Parts and Fabrication: ~$80–$120

Grand Total: ~$36,100

Actual out-of-pocket costs will remain under course limits since most components are low-cost and lab equipment (e.g., power supplies, meters, soldering tools) is provided.

3.2 Schedule:

Below is a schedule of what we expect to complete by the end of the semester:

Week	Date Range	Tasks	Responsible Member
Week 1	Sept 2 – Sept 8	Finalize project idea, complete proposal draft, assign subsystem responsibilities	All
Week 2	Sept 9 – Sept 15	Research IMU (accelerometer/gyro) and ESP32-S3 microcontroller capabilities; draft block diagram and subsystem overview	Ayman, Adam

Week 3	Sept 16 – Sept 22	Order initial parts (ESP32-S3, IMU, regulators, motor driver, switches); finalize visual aid; complete Design Document draft	All
Week 4	Sept 23 – Sept 29	Begin sensor interfacing on breadboard (I^2C communication test between IMU and ESP32)	Ayman
Week 5	Sept 30 – Oct 6	Implement crash detection thresholds in program; test IMU sampling rates; simulate impact events	Ayman
Week 6	Oct 7 – Oct 13	Design and simulate safety cutoff circuit using L298N driver; test manual reset button logic	Muhammad, Adam
Week 7	Oct 14 – Oct 20	Prototype voltage regulation subsystem (12 V to 5 V and 3.3 V) test with sensors and MCU	Muhammad
Week 8	Oct 21 – Oct 27	Integrate program crash logic with cutoff circuit; test motor cutoff timing and false-trigger behavior	Adam
Week 9	Oct 28 – Nov 3	Integrate throttle input to verify system reset logic	Adam
Week 10	Nov 4 – Nov 10	Assemble prototype PCB and enclosure; begin integrated system testing on bench setup	All
Week 11	Nov 11 – Nov 17	Verify tolerance with testing and log IMU data to confirm crash	Ayman

		response accuracy	
Week 12	Nov 18 – Nov 24	Perform final testing with simulated crash and rollover conditions; refine thresholds	Adam
Week 13	Nov 25 – Dec 1	Prepare for design review presentation; finalize documentation, diagrams, and test results	Ayman, Muhammad
Week 14	Dec 2 – Dec 8	Incorporate TA feedback; complete final integration and reliability tests	All
Week 15	Dec 9 – Dec 13	Prepare and submit final report; demo final	All

4. Discussion of Ethics and Safety:

4.1 Ethics

Our project follows the principles outlined in the IEEE and ACM Codes of Ethics, prioritizing user safety, fairness, and responsible engineering practices throughout the design and testing process.

4.1.1 IEEE Code of Ethics #1: Safety

We will prioritize the safety of the rider and surrounding environment at all times. All testing will occur under controlled conditions to prevent any danger to users or bystanders. Sensors and electronics will be securely mounted to the e-bike frame to prevent interference with normal riding. Because our system interacts directly with the motor control line, fail-safe logic will ensure the motor defaults to an off state if a hardware or firmware malfunction occurs. Proper electrical safety measures, including fuses, current limiting, and thermal protection, will be implemented to prevent shorts, overheating, or electrical fires.

4.1.2 IEEE Code of Ethics #5: Avoid Harmful Effects

We will minimize unintended motor cutoffs that could inconvenience or startle riders by carefully calibrating our accelerometer and gyroscope thresholds. Extensive bench testing and real-world trials will be used to distinguish normal road vibrations and bumps from actual crash events. This approach helps reduce false positives and ensures that the cutoff only activates during legitimate emergencies.

4.1.3 IEEE Code of Ethics #9: Privacy and Security

If future versions of the system include Bluetooth or smartphone notifications, all data transmission will use secure protocols. Only the intended user or designated emergency contacts will receive crash alerts. No personal or location data will be collected or stored unnecessarily.

4.1.4 ACM Code of Ethics 2.5: Fairness and Non-Discrimination

The system is designed to be modular and compatible with a wide range of e-bikes, regardless of brand or configuration. We will ensure that the system's detection logic and mounting design do not disadvantage certain users or bike types, maintaining fairness and accessibility in deployment.

4.2 Risk Analysis

The main risks in our design involve electrical safety, false triggering, and mechanical integrity during operation or testing.

4.2.1 Electrical Hazards:

The system uses a 12 V DC supply and low-voltage regulators. Short circuits or regulator faults could lead to overheating or component damage. We will mitigate this through proper fusing, current-limiting resistors, thermal protection in the regulators, and adherence to safe wiring practices (insulated connections, strain relief, and grounding).

4.2.2 Battery and Power Risks:

If a rechargeable lithium-ion battery is used for testing, over-discharge or shorting may cause thermal runaway. To reduce this risk, we will operate the battery within rated voltage limits, include inline fuses, and conduct charging and discharge tests under supervision with fire-safe containment.

4.2.3 False Crash Detection:

A false trigger of the cutoff could unexpectedly disable the motor during riding. This risk will be minimized through threshold tuning, sensor filtering, and multi-axis data validation so that only genuine impact or rollover events initiate cutoff.

4.2.4 Mechanical Risks:

Improper mounting could cause sensor modules or wiring to loosen and interfere with bike operation. All components will be secured with vibration-resistant fasteners or adhesive mounting pads, and enclosure designs will be tested for durability.

4.2.5 Human Interaction Risks:

Reset and cutoff buttons will be placed away from moving parts and high-voltage areas. Users will be informed of the system's behavior before testing to prevent surprise activation.

Overall, each identified risk has been addressed with concrete design or procedural safeguards. The system defaults to a safe, motor-off state in the event of software failure, sensor loss, or power anomaly, ensuring that no single point of failure can endanger the rider.

5. Citations:

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