Bike Crash Detection

ECE 445 Design Document

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1 Introduction

1.1 Objective

Biking has become a vital means of transportation. In 2017, approximately 47.5 million Americans cycled on a regular basis [13]. In 2015, there were 467,000 reported accidents involving bicycles [3]. Pedalcyclist fatalities in 2017 made up 2.1% of all traffic related deaths in 2017 [4]. There have been many expensive and inexpensive innovations to increase communication between cyclists and motor vehicles such as the Varia Rearview Radar ($200) [2] and the Zackees Turn-Signal Gloves ($60) [7], but the overall deaths per year in motor vehicle accidents involving pedal cyclists continues to increase [4]. Of all pedalcyclist deaths caused by motor vehicles, 82% involved the front of the vehicle [4], indicating that visibility is not the main issue in the crash. From 2000 to 2013 commuting rates increased 105% [5]. In these situations, it is rare for cyclists to ride in groups. Group riding not only makes the cycler more visible, it also allows for the rider to gain help immediately. Since this is not the situation for the majority of riders, a device to communicate with emergency contacts in the event of a crash would be beneficial. Cyclists lack the safety innovations that many modern cars benefit from such as the OnStar safety and notification system. There are devices for the bicycles that detect crashes, such as the Garmin Edge 530, one of the most inexpensive options at $300 [8]. However, there is no solo inexpensive device that offers these capabilities without the expensive overhead of active GPS for navigation and hardware to communicate with bike sensors or the rider's smartphone. Our device caters directly to commuters who have no need for expensive hardware to measure performance.

Our goal is to develop a device that can allow cyclists to have access to the critical care immediately after the accident. It would be beneficial for many bikers to have a device that can detect when they are involved in a crash, and notify an emergency contact via text message of the severity of the crash so that the rider can get assistance. Many current solutions rely on devices that attach to helmets, but only 17% of all cycling fatalities involved a helmet [6]. A no hassle solution that is guaranteed to stay on the bike will ensure that the device is present when an accident inevitably occurs. Our solution will attach to the bike seat post and detect for crashes based on acceleration and rotations. It will then determine the rider's location and send a notification to the rider's emergency contact with the details of the accident. Our solution will be entirely self-contained and not rely on a connection to the rider's smartphone or other technology on the bicycle.

1.2 Background

Right now there are no low-cost, attached to bike solutions for accident detection and handling. Devices on the market are traditionally attached to the helmet. However most cyclists do not use a helmet making it impractical to have an accident detection device on the helmet. Attaching the device to the bicycle ensures that the device will be there when need be. Furthermore, to ensure that as many cyclists have access to it, we want to implement a cheap and durable option. A helmet solution costs $50 or more [1] making it impractical to purchase for most consumers.

1.3 High-Level Requirements

- The device must accurately detect a crash with over 1g of force and distinguish crashes from simply dropping the bike or sudden controlled stops.
- The device must quickly send a message within 1 minute of the crash to emergency contact(s) with relevant information from the accident, specifically the time, location, and severity of the crash.
- Device must be durable to survive crashes and be easily mountable to 95% of commuter bikes without inhibiting the rider.

2 Design

2.1 Physical Design

Our device will mount to the seat post of bikes (Figure 2). These posts range in diameter from 22mm to 35mm [14]. To accommodate this variance, we will use a quick-release clamp (Figure 3) to attach to the post. The board will be oriented parallel to the seat post, and will be contained within a protective case. The dimensions of the case are still to be determined, but the case will be rectangular, with a narrow width perpendicular to the post, a longer length parallel to the post, and a shallow depth determined by the PCB thickness and battery. This is to minimize the chance that the device will make physical contact with the ground in the event of a crash, reducing the chance of impact damage.

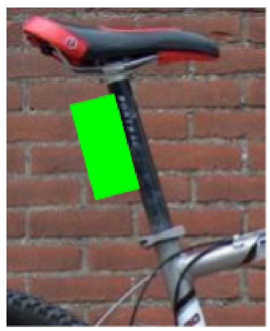

Figure 2: Attachment point on bike
Source: CC BY-SA 3.0, https://en.wikipedia.org/w/index.php?curid=10252056

Figure 3: Quick release clamp used to attach device case to bike post
Source: https://www.amazon.com/Aluminum-Bicycle-Release-Seatpost-Mountain/dp/B074P38GQ2

2.2 Block Diagram

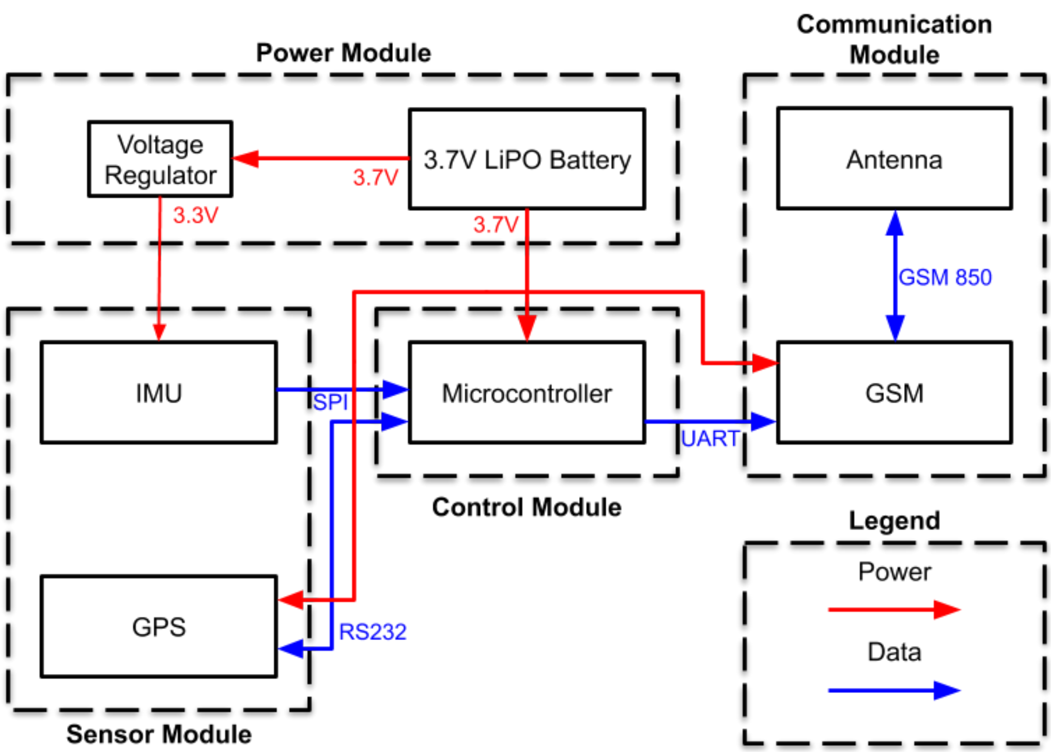

Figure 1: Block Diagram

The device has four main modules: Power, Control, Sensor, and Communication. The Power Module contains the power supply, a 3.7V LiPO battery, and a voltage regulator to step down to 3.3V for supply to the IMU. The Control Module consists solely of the microcontroller, which interfaces with the sensors and communication module. The Sensor Module consists of the IMU and GPS chips, which are used by the microcontroller to detect crashes and location. The Communication Module contains the GSM chip and antenna that will be used to connect to a cellular network in order to send text messages.

2.3 Subsystems, Requirements, and Verifications

2.3.1 Power Module

The main power source will be a 3.7V LiPO battery. This will provide power directly to the microcontroller, GPS, and GSM chips and will be easily accessible to the user for recharging when the battery is out of power. The current requirement comes from the requirements for all the chips on the board. The Microcontroller draws a max of 14mA, the GSM draws up to 100mA when sending a text message, the GPS draws a max of 67mA when acquiring its position, and the IMU has a typical draw of 3mA. There will also be a voltage regulator to convert from the 3.7V supply to 3.3V. The 3.3V will power the IMU, GPS, and microcontroller. The current requirements come from the requirements for this chip, and must be able to supply 150mA.

The battery has a capacity of 2500mAh. Current draw during normal activity without a crash is less than 20mA, as we only have to power the microcontroller and IMU. Therefore the battery should last at least 100 hours before requiring recharging.

Table 1: Power Module R/V

Requirement	Verification
Must provide ≥200mA between 3.6V-3.9V for the ICs and voltage regulator	1. Connect fully charged battery to a fixed load 2. Discharge battery and monitor voltage with a voltmeter.
3.3V regulator must provide ≥150mA between 3V-3.45V	1. Connect regulators to battery at input, and loads at each output. 2. Discharge battery and monitor voltage at both outputs with a voltmeter.
Must provide 20mA between 3.6V-3.9V for 100 hours	1. Connect fully charged battery to a load of 185Ω, to draw 20mA at 3.7V. 2. Record voltage across battery every ten hours for the first 90 hours, and every hour afterwards.

2.3.2 Control Module

The microcontroller will be an ATmega2560, and will be used to process the IMU data, communicate with the GPS chip, and control the GSM chip using three parallel serial connections. The microcontroller will be responsible for identifying a crash using the IMU data, parsing the location from the GPS data, and controlling the GSM to send a text with the relevant information.

Table 2: Control Module R/V

Requirement	Verification
Must communicate over three hardware serial ports simultaneously	Connect three serial ports to the three ICs and verify active communication to all three

Must communicate at speeds over 1MHz with the IMU over SPI	Record the number of readings in a fixed time frame and check that the date rate is sufficient

2.3.3 Sensor Module

The IMU will be an ICM-20689 chip, that contains a 3-axis accelerometer and a 3-axis gyroscope. Both have programmable limits that will be tuned as needed to accurately detect crashes. According to Stone and Broughton, fatalities on bicycles increases from 3% to 10% when vehicle speeds 30mph to 50mph [10]. This speed coreleates to 10g of acceleration in a normal crash with an average adult male [11]. The data will be smoothed by a software implemented filter, initially planned to be a moving-average filter.

The GPS will be a NEO-6M GPS Module, that can communicate over a serial interface with the microcontroller to report the location of the device when a crash occurs. The chip will not always be active in order to reduce power consumption, and will be turned on when an event is detected by the IMU.

Table 3: Sensor Module R/V

Requirement	Verification
Must accurately report accelerations under 10g and rotations under 500dps	To test 1g, we will drop the IMU in the housing from 1ft. To test higher values, attach the IMU to a vehicle and accelerate the vehicle to 25 mph and decelerate at progrisively faster rates in an empty parking lot. A team meber will time the decelaration from outside of the vehicle. The IMU will be outputing constant values. Those values will be graphed and compared to the calculated accleration.
Must provide GPS data in NMEA format accurate to within 10 meters	Parse the acquisition data to ensure the correct encoding and manually verify accuracy of location data when outside

2.3.4 Communication Module

The GSM will be a SIM800L module, which will receive data from the microcontroller on when to send a text message. The GSM module will communicate with the antenna to send the message over a cellular network.

Table 4: Communication Module R/V

Requirement	Verification
Must connect to a 2G cellular network in populated areas	Confirm that the SIM card can communicate with the network in various locations around campus
Must be able to send a text message within 1 minute of detecting a crash	Simulate conditions for a crash and measure the time for the system to send the notification

2.3 Tolerance Analysis

As there are several different types of crashes and severities, we want to correctly identify the crash. The most important crash we must detect is one that renders the rider unable to contact anyone making the device mandatory to work. A critical crash is when a collision occurs when the bike is travelling around 10[m/s], and sends the rider flying. Say we go from 10[m/s] to 0[m/s] in a time frame of .1 seconds, we can calculate the g's of the crash using a/g where a = (10[m/s]/.1[s]), and g = 9.8[m/s^2]. We get the calculation of (10/.1)/9.8 = 10.2[g's] experienced during the impact.

The minimum threshold for a crash is moving at a speed of 1[m/s] to 0 [m/s] in a timeframe of .5 seconds. The g's experienced in this crash is (1/.1)/9.8 = 1.02[g's].

However the g's experienced by a bike is not enough to accurately detect a crash. The minimum threshold above can be experienced in a controlled stop while biking. Therefore measurements by our gyroscope is used to complement the g measurements. If our gyroscope measures more than a 45dps rotation complemented by the minimum threshold for a crash of 1g, our system will detect a crash.

As our IMU is constantly streaming this data we will have to make sense of the constant stream of data. We will make the calculations for g-force every half second and grab the dps measurement every second. At the end of every second, if at any point during that timeframe, the dps and g-force meet our minimum threshold, we will detect a crash and send a notification.

2.4 Flowchart

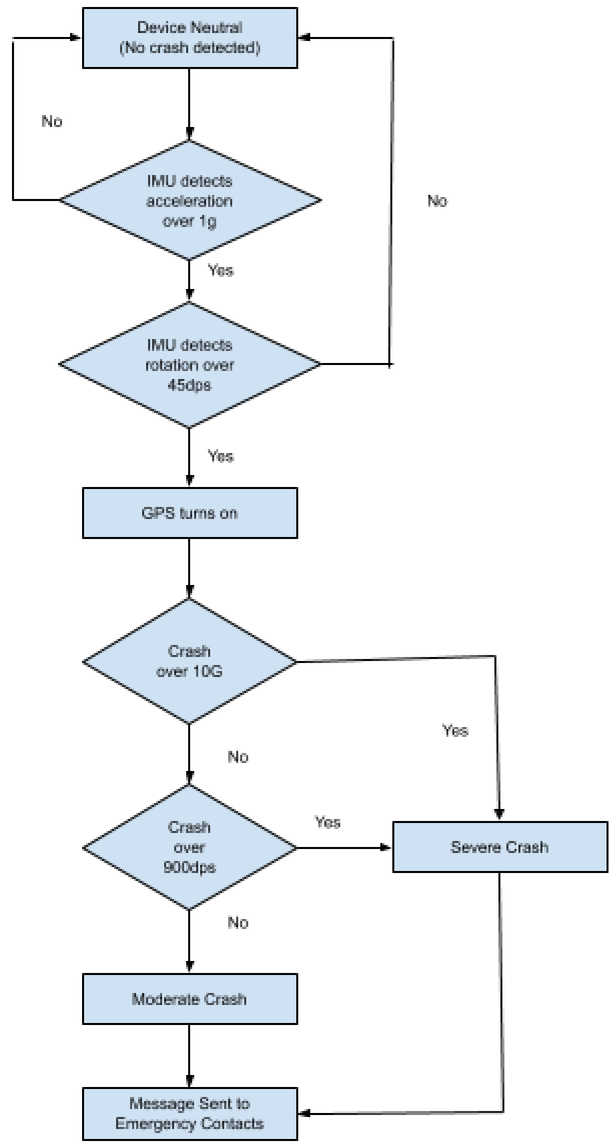

Figure 4: Control Flowchart

This flowchart (Figure 4) outlines the logic the microprocessor will follow to determine the event of a crash and the actions it will take in the following moments. The IMU will constantly be reporting data to the microcontroller. When the IMU reports a high g-force (>1 g), there is a possibility of an impact. However, the microprocessor will not identify a crash unless the sudden acceleration is accompanied by a significant rotation (>45 dps) by the bike as reported by the gyroscope. This is to filter out sudden stops that can involve high acceleration where the rider maintains control and keeps the bike upright. If both high acceleration and significant rotation are reported, the microprocessor will determine that a crash has occurred and begin the notification process. The GPS will be turned on and the current location will be recorded.

Additionally, the microprocessor will categorize the severity of the crash depending on the magnitude of both the acceleration and rotation. Once all of this information has been gathered, the microcontroller will instruct the GSM to send a text message with this information to the emergency contact(s) designated.

2.5 Circuit Schematic

2.5.1 Power Circuit

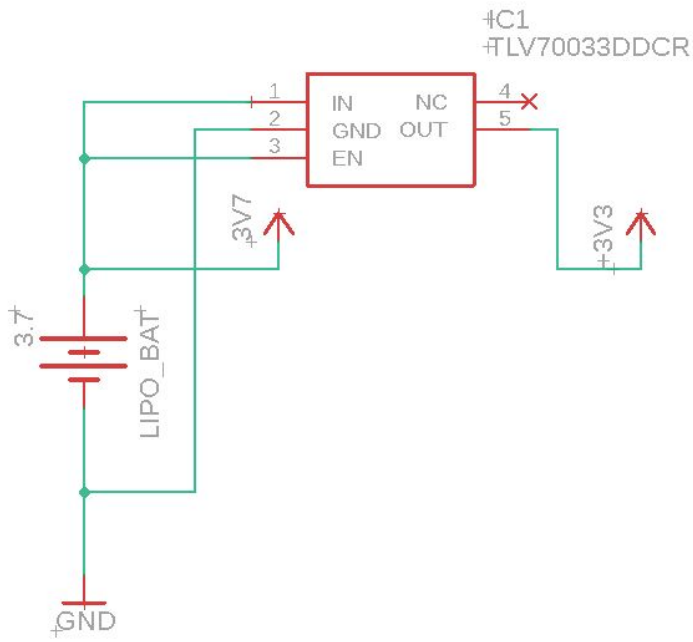

Figure 5: Power Circuit Schematic

This diagram illustrates the power subsection of the device. The device will be powered via a 3.7 V, 2500 mAh Lipo battery which allows for the system to be easily rechargeable. The GSM module requires 2 amp bursts and therefore a Lipo battery was chosen. The GPS, GSM, and microcontroller modules will all be powered directly by the battery as all of them have built in tolerances to allow for 3.7V. The IMU requires 3.3V so a voltage regulator step down(IC1) will be utilized.

2.5.2 Data Circuit

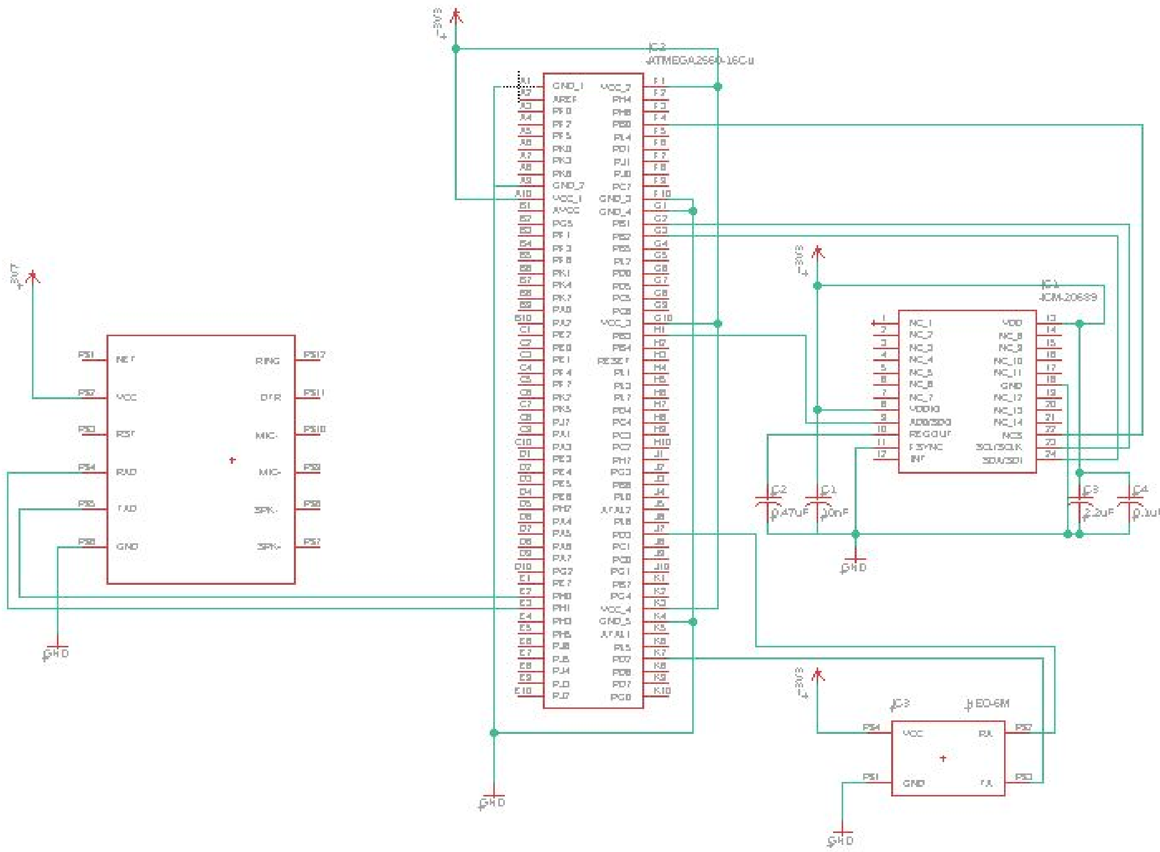

Figure 6: Data Circuit Schematic

This diagram shows the data connections and power between microcontroller (IC2) and the IMU (IC1) which will be supplying 9-axis of data. In addition the microcontroller (IC2) communicates with GPS module (IC3) in order to receive the devices current location in the event of a crash. Lastly the microcontroller (IC2) will also communicate with the GSM (IC4) in order to send a text message to the list of emergency contacts.

2.6 Filtering

Due to the nature of the IMU, signal processing will be an essential part of data analysis. T. Islam outlines two different analysis methods of IMU data in “Comparison of complementary and Kalman filter based data fusion for attitude heading regerence system” [14]. The complementary system was chosen due to the computation needs of the Kalman filtering method. The complementary system is based on the theory that acceleration data is only valid on the long term and gyroscope data is only valid in the short term. Using a simple LPF, the accelerometer data is filtered and the gyroscope data will undergo numerical integration followed by an HPF. The filtered accelerometer data is summed with the gyroscopic data with the formula angle = .98 * (angle + gyroscopicData*dt) + .02 * (accelerometerData). This formula combines 98% of the past angular data with 2% of the change due to the new acceleration. These percentages will be modified from experimental data. Acceleration data will also be passed through an HPF to view short term acceleration inorder to ensure that a crash is detected.

2.7 Future Design Elements

Future iterations of this design will utilize Bluetooth to connect the device to a simple mobile app. This app will allow for easier modification of the emergency contact list as well as contains an indicator for the battery to tell the consumer when the device must be recharged. The app will also contain settings like a virtual bike lock setting that would automatically text the location of the bike every 2 minutes to the user in the event that their bike was moved without their knowledge. The lock will automatically be disabled when the user is within 5 feet of their bike. This is determined using bluetooth’s direction capabilities.

3 Cost and Schedule

3.1 Cost Analysis

Table 5: Cost Analysis

Part #	Mft	Desc	For	Price	Qty	Total
ICM 20689	InvenSense	6-axis MotionTracking device that combines a 3-axis gyroscope, 3-axis accelerometer	Sensor	$ 4.00	1	$ 4.00
ATmega328	Atmel	8-bit AVR microcontroller	Control	$ 11.85	1	$ 11.85
SIM800L	SIM Tech	Quad-band Mini GPRS GSM	Communication	$ 12.73	1	$ 12.73
Neo-6M	Ublox	6 GPS module ROM, crystal	Communication	$ 5.75	1	$ 5.75
511-L7805ACV	STMicroelectronics	Linear Voltage Regulators 5.0V 1.0A Positive	Power	$ 0.57	1	$ 0.57
LD1117V33	STMicroelectronics	IC REG LINEAR 3.3V 800MA TO220AB	Power	$ 0.55	1	$ 0.55
Labor	UIUC	3 students for 10 weeks at 10 hours/week	Labor	$ 10.00	300	$ 3,000.00
Total						$ 3,035.45

3.2 Schedule

Table 6: Schedule

Week	Alex	Dhruv	Brian
9/25	• Research Components for GPS and GSM • Research Tolerances	• Research Power Supply and Microcontroller • Begin Mechanical Design • Sign up for Design Review	• Research Safety & Ethics
10/3	• Finalize Parts Order	• Begin communication between GSM and	• Finalize Parts Order

	● Begin communication between GSM and microcontroller	microcontroller ● Begin Circuit Design	● Finalize Tolerance analysis
10/10	● Continue working on communication code	● Prototype 3D model ● Test durability	● Begin PCB Design
10/17	● Finalize communication code	● Finalize Mechanical Design ● Test Crash Detection Code without enclosure	● Finalize PCB
10/24	● Construct device without PCB	● Print finalized 3D enclosure ● Mechanical attachment	● Submit PCB order
10/31	● Begin user interface	● Test device on bike	● Rework PCB
11/7	● Rework tolerances ● GSM testing	● Test durability of device ●	● Submit any changes to the PCB
11/14	● Continue GSM testing	● Continue Testing	● Test fall without crash detection
11/21	● Finalize user interface	● Continue Testing	● Continue Testing
11/28	Fall Break	Fall Break	Fall Break
12/5	Demo	Demo	Demo

4 Safety and Ethics

Our device will be used exclusively outdoors so it must be able to survive continued exposure to the elements. The protective case for our circuit will be IP54 rated. This means the case will have partial protection from dust and protected from water splashes from all angles. The water protection is crucial as the device will be located behind the seat post which is exposed to water caused by movement of the rear wheel.

As our device will be transmitting data to external sources, we must respect privacy as stated in the ACM Code of Ethics 1.6 [9]. This means that we must only collect the minimum amount of information to make our device work. Our device will require a name, emergency contacts, and current location. The last piece of personal information, location, will only be tracked after the device is activated after a crash is detected which protects the riders privacy.

ACM Code of Ethics 1.2 [9], states that the device should do no harm. The device will not directly contact Emergency Services which mitigates any false alarms. The device instead contacts emergency contacts which allows for a human intermediate to first make the decision whether emergency services is needed.

Lastly, we should “be honest and realistic in stating claims or estimates based on the available data,” according to ACM Code of Ethics 1.3 [9] . As we are detecting data from our gyroscope and accelerometer, we need to provide accurate guidelines and limits for crash detection. Therefore we must find the threshold in our data set that distinguishes between a crash and normal usage of the bike. This device does not replace a rider’s responsibility to call 911 in the event of a severe crash.

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