UNIVERSITY OF ILLINOIS AT
URBANA-CHAMPAIGN

ECE 445 : Project Safe-Tee

DESIGN DOCUMENT

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1 Introduction

1.1 Problem and Solution Overview

Currently, cyclists and those who use alternative transportation face many difficulties while on the road. One of the main difficulties is the lack of vision and ability to communicate intentions such as turning and stopping using hand signals, especially when it is dark. Our goal is to avoid these unnecessary fatalities by producing a standard for all of those who wish to travel the roads in a medium other than a motorized vehicle.

We will achieve this goal by building and developing a universal jacket that can be used for both adults and children. Usage of the jacket will not only be available for cyclists but also be available for those who look to use scooters, skateboards, and other types of alternative transportation. The jacket will provide users with an intuitive gesturing system, that allows others on the road to see a clear indicator of their intended movements. Further, the jacket's smart motion sensors will provide a separate braking signal that will be displayed when the user is slowing down. Each of these indicators and sensors will be represented by LEDs that are not only bright but also intuitive for others to understand, allowing for clearer communication for all on the road.

1.2 Background

In this day and age, approximately 100 million Americans ride their bikes each year, with over 14 million Americans riding two or more times per week [9]. However, those who go for leisurely rides or commute via cycling ride under the threat of an inherent safety risk while sharing the road with cars and other larger vehicles. Although bike lanes have begun to pop up from time to time, cyclist fatalities have risen over 10% in 2018, with the current estimation by the NHTSA is 857 fatalities in 2018 [8] [1].

Current structures and solutions that exist have helped but have not done enough to mitigate the damage. One of such is the universal hand gestures that are taught in traffic school, with the left hand out meaning a left turn, left hand out and up meaning a right turn, and left hand out and down meaning a brake. However, these gestures have become less and less well known, and even using these become less effective in the dark. While other solutions look to combat the same problem, such as a company called Blinkers, they prove not effective enough and can fail out of business [10]. Further, none of these solutions have the added capability of controlling the functionality based upon the actions of the user, while our product looks to incorporate a brake light based upon the speed of the user. Our product will do this as well as combine the simplicity of gesturing with the added visibility of the Blinker product. These efforts will be towards reducing the number of fatalities to zero.

1.3 Visual Aid

We can see in figure a visual representation of our problem statement. The user (represented as the yellow rectangle) wants to follow the blue arrow path to bike home. In

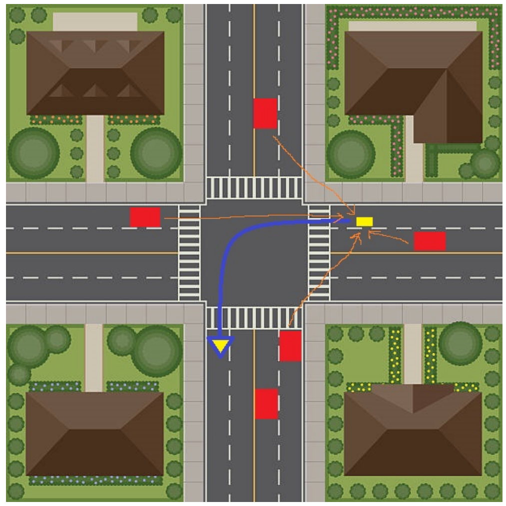

Figure 1: Visual example of a possible use case.

order to complete this road crossing, the user would like to indicate to the cars on the road (the red rectangles) that he/she intends to make a left turn. By holding his/her left arm in the designated gesture, the drivers of the cars are able to see and interpret the bikers next actions. This is especially true in low light conditions, where visibility is limited. Since we plan to use LED's that are visible both in front and behind the user, each of the four cars that pose to highest risk to the biker can see and understand that they must be cautious about the bikers movements.

1.4 High Level Requirements

- The turn indicators should become active within 2 seconds once a user holds a turn gesture, specifically that they raise either hand by more than 70 degrees relative to their torso.
- The brake indicator should become active when the user decelerates at a rate greater than 2 m/s^2. [4]
- The LEDs should produce 10 lumens of visible light energy in order to match bicycle light standards and be visible to others on the road. [11]

2 Design

2.1 Block Diagram

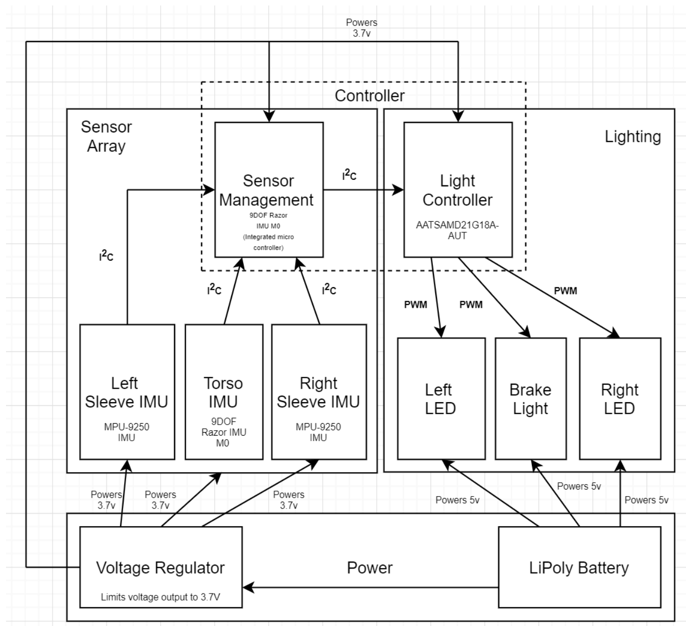

Figure 2: Block Diagram model outlining the interconnections between the four subsystems in our design: Power, Sensors, Control, and Lighting.

2.2 Physical Design

Figure 3: Diagram of how our design will be physically laid out on a jacket.

2.3 Subsystems

2.3.1 Sensory Data Ingestion

IMU Array
We plan to use a series of three 9-DOF Inertial Measurement Units or IMUs that combine an accelerometer, gyroscope, and compass into one package that we will be able to use to determine a user's movements in 3D space. These sensors will be placed strategically such that we can isolate hand and arm movements from the motion of the person as they are travelling down the road. To do so, we plan to utilize two IMUs placed on either sleeve of the jacket, both of which are connected to a central control unit with a SAMD21 micro-controller via I^2C. In order to discern a user's hand movements from their overall movement in the environment, we will also have a third IMU that is attached on the back of the jacket on the user's torso. This will give us a reference frame of movement for the user, and allow us to isolate their hand movements and gestures. We have chosen to use MPU-9250 IMUs for this purpose, because they are widely used in the community and are known for their reliability and ease of use, and also because they come in many packages which will allow us to connect three IMUs together and perform real-time calculations.

Sensor Management Unit
For our purposes, we plan to use two simple breakout boards that expose the communication and power pins on the boards for the IMUs on the sleeves, and an integrated board with an IMU and a SAMD21 micro-controller for the torso sensor which will communicate with all three IMUs using I^2C and implement the sensor data ingestion control logic. This unit will ingest the data from each of the sensors and discern user

gestures from their movement and orientation, and then indicate the state of the system via serial to the LED Control Unit, which will then handle the generation of outputs.

Requirement: The Sensor Management subsystem should be able to read and parse 9-DOF data from the IMUs at a rate of at least 5Hz to ensure accurate and low-latency gesture identification.

2.3.2 LED Output Generation

LED Control Unit

In order to maximize visibility, we have decided to use a series of LED strips to indicate the directional intent of the user. More specifically, our design calls for LED strips fashioned as rings around the biceps of each arm and around the user's torso. This way, when the user raises their arms to indicate that they want to turn in a certain direction, others are able to see the LEDs in all directions around the user. We plan to use individually addressable RGB-LED strips, which will allow us to create some more complex animations in order to communicate user intent, such as turning and braking. A combination of color, blinking, and movement will be generated by the LED Control Unit based on the inputs provided over a serial input from the Sensor Control Unit. The LEDs will also be controlled by a SAMD21 micro-controller, however this one will be mounted on a custom PCB that provides access to the LED control pins for each of the strips used in the design. We plan to design this board to provide easy access to all of the LEDs at once and allow us to update them as quickly as possible.

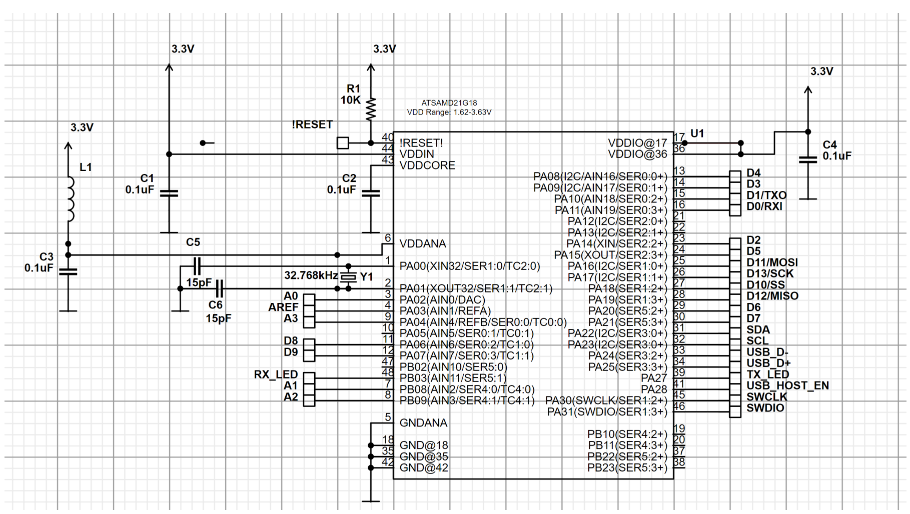

Figure 4: Draft circuit schematic based upon the datasheet with respect to typical usage. This will go into our PCB.

LED Array

The specific LEDs we plan to use are modular strips that can be easily cut and attached, and that provide individually addressable access to the LEDs, which will give us the most flexibility in designing a cohesive look and feel of the system and make the electrical connections simpler and more robust on a soft-shell jacket. Also, this means that we can produce more complex output patterns on the LEDs which can be used to communicate user intent. Examples of these may include different colors for different actions, such as turning and braking, and simple animations to indicate the direction that a user is moving in. These lights have an expected current draw is 600mA for a 1-meter strip of LEDs, which falls within the expected range of our prospective power supply. After evaluating the actual power draw of the system, it is possible that we will need to add additional power infrastructure to allow for delivering more energy to the LEDs, but this is something that we are prepared to evaluate and decide on later on in the project process.

Requirement: The LED subsystem must be driven such that it provides light indicators brighter than 10 lumens to ensure visibility in unobscured conditions in accordance with other bike lights available on the market today.

2.3.3 Power System

An independent power supply is necessary to provide power to the electrical components on board our jacket. This includes the LEDs, IMUs, and micro-controllers. We have decided to use a LiPoly battery as the primary power supply, since they are compact and light, and have a high capacity. They are also rechargeable, which will reduce the cost for the user to keep the jacket in operation and improve the longevity of the product. The power supply will be located on the back of the jacket near the torso, which will be easily accessible to recharge.

Specifically, we are considering using a LiPoly battery that is rated for a nominal 3.7V at 1Ah, which matches the power specifications for the micro-controllers and sensors that we plan to use, and also is powerful enough to be used by the LEDs that we have chosen.

Requirement: We anticipate needing at least 3 watts of power, but this may be adjusted after we have assessed the system draw in practice.

2.4 Tolerance Analysis

We believe that the module that will pose the most challenges to developing our design is the Sensor Data Ingestion Unit. The most difficult requirements to meet will be ingesting and manipulating the orientation data such that we can obtain a measurement accurate to within 10% of the physical orientation, and at a rate of at least 5Hz. To confirm that we will be able to meet these requirements, we will use the specifications of the parts that we've chosen and determine an upper bound theoretical accuracy and refresh rate. Before commencing on building our prototype, we will first ensure that the component specifications will match the requirements stated above.

Based on the specifications for the IMUs used in our design, the MPU-9250, we see that in normal operation mode the chip is capable of reporting 9-DOF orientation at a rate of 1kHz. Note that the I^2C bus on the chip is rated to run at 100kHz, which should allow us to read samples from the sensor at nearly its own sample rate.

In order to avoid erroneous readings due to noise, we plan to implement some simple filtering operations in software that will prevent spikes that might affect operation. While in practice we will use a median filter, rolling average or something similar that reports at the same rate as the IMU (excluding computational delay), for the purposes of this calculation we can use the upper-bound or worst case of such a filtering operation. This implies that we produce only one filtered sample from a single set of input samples within the time domain of the filter. The effective rate of the output samples would then be

$$\frac{\text{1kHz}}{\text{window size}}$$

In order to determine an acceptable window size, we need to analyze the accuracy constraints of the IMU. Based on the specifications, in the lowest-power mode this IMU has an range of $\pm 250^\circ/\text{sec}$. In order to meet our requirement of a maximum deviation of 5°, this implies that the filtered samples must be accurate to within 1% of the total range of 500°. Some prior attempts to filter noise from IMU data with similar specifications have been made [3]. These indicate that a suitable window size for this kind of application would be 10 samples [3].

Based on this window size, we can compute an effective filtered sampling rate of 100Hz. Given that our requirement is to discern gestures with a 5Hz refresh rate, we can determine the time window that our software implementation of gesture detection needs to run for any arbitrary sample is as follows

$$\frac{1}{5\text{Hz}} - \frac{1}{100} = 0.19\text{s}$$

Given that the Atmel SAMD21 can run on a potential clock speed of up to 48MHz, we believe that our software implementation of gesture detection should be able to run substantially faster than 0.19s per filtered sample, indicating the viability of our design.

2.5 Requirements and Verification

Requirement Summary for Project Safe-Tee

Sensors: 15 points

- This unit must be able to ingest orientation, acceleration, and directional data from the attached IMUs and discern user gestures as they are made, in order to generate output signals that will be decoded by the LED Control Unit.

LEDs: 15 points

- This module must take the output signals from the Sensory Control Unit and produce the corresponding lighting cues and animations necessary to signal the user's intent to others on the road.

Power System: 10 points

- This module must meet the minimum requirements of supplied power for all of the electrical modules in the design, and supply enough steady power to power each circuit.

User Experience: 10 points

- Jacket should be easy to operate and to charge, and provide users with a simple and intuitive way to indicate intent on the road while not in a vehicle.

Total Points: 50

2.5.1 Sensors

9-DOF IMUs

Requirements	Verification
IMUs should report 9-DOF orientation data at a rate of at least 5Hz in order to track movements made by the user and accurately discern left turn and right turn gestures.	We will obtain the reported values of the 9-DOF over a serial connection and measure the number of updates over a fixed time interval of 10 seconds.
The IMU orientation measurement granularity should be smaller than 5 degrees. This will allow us to discern the difference between gestures that are similar to a user raising their hands to turn, such as holding the handlebars.	We will take a series of IMU measurements and change the orientation of the device slowly until we can register a consistent difference in the reported value, the physical angle of this adjustment represents the granularity of the IMU measurement.
Sensor should be able to report the angle of the hand/arm relative to the torso within an accuracy of 10%.	We will hold our arm at various orientations relative to the torso. We will measure the true angle with a protractor and compare with the reported angle.
Sensor should be able to detect linear acceleration/deceleration with an accuracy within 10%.	We will compare measurements from the sensor data compared to known measurements of specific circumstances such as gravity.

Sensor Control Unit Software

Requirements	Verification
Software should be able to calculate a rolling average of the data from the 9-DOF IMUs over a fixed time interval in order to filter out noise of the sensors.	We will inspect the output of the software and compare it with the corresponding expected value.
Software will move through a simple finite state machine between an idling state, right turn state, and left turn state.	We will produce the inputs required and compare the outputted state to the expected state.
The software should be able to communicate its current state information to another microcontroller (Light Controller) over a simple serial connection.	We will verify that the microcontroller can communicate this info serially by inspecting the output signals and seeing if we can recover the data transmitted.

2.5.2 LEDs

LED Array

Requirements	Verification
LEDs should produce at least 10 lumens of light energy when fullypowered on and set to the color white.	We will use a Lux meter to verify this requirement directly.
LED indicators should be visible to others both in front and behind the user.	After the LEDs have been mounted on the jacket, we will verify this requirement by inspection.

LED Control Unit

Requirements	Verification
The software should be able to receive current-state data from another microcontroller (Sensor Controller) over a simple serial connection.	We will verify that the microcontroller can communicate this info serially by producing a set of test input signals and seeing if we can recover the data transmitted.
The software should be able to produce a PWM signal that is sent to the LED Array to produce the appropriate RGB coloring for any arbitrary LED.	We will verify this by writing test code to generate an arbitrary PWM signal and inspecting the corresponding color of the lights.

2.5.3 Power

Requirements	Verification
The lithium polymer battery with the assistance of the voltage regulator circuit should be able to provide a constant 5V of power.	We will directly inspect the power output from our power system over an extended period of time and under different usage constraints.
The battery should power to the jacket for a minimum of an hour.	We will leave the jacket on ant time how long the battery lasts.
The jacket should have an ON/OFF switch enabling the user to save battery when not in use.	We will check the power to each of the on-board components when the switch is in the OFF and ON positions.

2.5.4 User Experience

Requirements	Verification
The user should be able to move comfortably without feeling restricted.	We will directly compare the mobility of our jacket with that of a normal jacket to determine if mobility is hindered in any way.
The gestures should be intuitive and responsive, such that the corresponding outputs are generated within 0.5sec of the gesture being performed.	We will perform the gesture and measure the response time of the system over 250, and confirm that that the P95 response time falls within this parameter.
The jacket should be charged easily without the need to open up the jacket or make any modifications.	The charging port should be easily accessible and visible on the back torso area of the jacket.

3 Cost and Schedule

3.1 Cost Analysis

We estimate that our fixed development costs come out to $50/hr, at about 8 hours of work per week. With our team of three, the project will be completed over a total of seven weeks, up until the mock demonstration. Therefore, our projected costs come out to:

$$3 \cdot \frac{\$50}{hr} \cdot \frac{8hr}{wks} \cdot 7wks \cdot 2.5 = \$21,000$$

We estimate that the total cost of the required parts and prototype PCB for a single unit come out to the following figures:

Table 1: Part Costs for the Prototype Unit

Parts	Cost
9DoF Razor IMU M0	$35.95
2x MPU-9250 IMU	$29.90
ATSAMD21G18A-AUT	$3.13
Lithium Ion Battery - 1Ah	$9.95
Adafruit NeoPixel Digital RGB LED Strip	$16.95
Assorted capacitors, resistors, ICs, sockets, crystals (Digikey; est.)	$10.00
Total	$109.88

Since we plan to develop one prototype jacket, out total cost amounts to $21,109.88. If we decided to mass produce this product, the total cost would be $42.26 per unit with a base production cost of $21,000.

Table 2: Part Costs for a Mass Produced Unit

Parts	Cost
3x MPU-9250	$8.70
Lithium Ion Battery - 1Ah	$9.95
2x ATSAMD21G18A-AUT	$5.16
Adafruit NeoPixel Digital RGB LED Strip	$13.40
Assorted capacitors, resistors, ICs, sockets, crystals (Digikey; est.)	$0.40
Total	$38.71

3.2 Schedule

In order to ensure that we will have the best chance of successfully completing this project, we have outlined the following schedule with 2 weeks of slack time to accommodate any issues that arise along the way. Our plan is to focus on hardware components first, and to make and finalize the PCB design before moving on to the software section. This is because hardware development is more risk prone than software development, and we will be able to make incremental progress on the software components while waiting on external parties/support for the hardware pieces (such as PCB printing, or waiting for parts to arrive).

Week	Tasks
2/24/20	Learn how to use EAGLE to design PCB, pick out parts for project. Unit test individual components.
3/2/20	Design and implement LED array PCB using EAGLE.
3/9/20	Attempt grab relevant data from our micro controller via the IMUs
3/23/20	Complete PCBway order. Begin implementing software which takes the data from the IMUs and instructs the LED array to light up accordingly.
3/30/20	Complete the software component of the project, and upload the code to the micro controllers.
4/6/20	Mount all sensors, chips, and power components onto jacket.
4/13/20	Extra time / Final Adjustments
4/20/20	Mock Demo
4/27/20	Final Demo

4 Discussion of Ethics and Safety

In the effort to create a product that is meant to save lives, it is important to consider the safety and ethical components of not only the creation of this project, but also the usage of it by the populus. While building the project, as we are working with electrical components, we run the risk of harm to ourselves and those around us. Our utmost concern will be laboratory training and safety with regards to the Division of Research Safety training [5].

Furthermore, when considering the production of our product, we must adhere strictly to Rule 3 of the IEEE Code of Ethics, which states that we must be "honest and realistic" with our claims with respect to available data [2]. Our plan of development includes extensive experimentation that allows for the easiest and most intuitive usage of Project Safe-Tee. The jacket must always light up when the user brings up his arm, as there is an even greater risk when the user thinks that others on the road can see his turning indicator when in fact they do not. Our project further must follow Rule 9 of the code of ethics, to ensure that our product will neither indirectly cause harm due to missing indicators nor directly cause harm due to malfunctions [2].

We are cognizant that there are multiple concerns that stem from the creation of the project that may directly cause harm to a user. One of the most obvious is short-circuits, as our device is an electrical one that is meant to be used outdoors. As a result, we will ensure that the internal components of our project will be dry while submerged up to 1 meter of water, adherent to the IP67 guidelines [6]. Finally, the LiPo battery is well known for its inherent safety risks, as it is not difficult to start a fire or even an explosion under certain circumstances. To combat this, we will ensure that the charger prevents overcharging outside of the 3.7V range, and we will tell the users basic safety tips, such as to wait for it to cool before charging it after usage, as well as to never leave the battery unattended while charging [7].

In order for our project to meet the criteria we've established, we plan to implement certain safety measures to mitigate risk to the user when the product is both in use and during charging. Firstly, In order to prevent the LiPo battery from overcharging, we plan use a voltage regulator to limit the output of our power source. To prevent the worst case scenario of thermal runaway, which would lead to the battery potentially exploding, we plan to encase the battery in a durable heat resistant material such as leather or mineral wool. Secondly, we decided to use LED's that are assembled in parallel as opposed to LED's assembled in series, so that one failed LED does not compromise the reliability of the product. This makes it so that unless every single diode fails simultaneously, the jacket will always light up when the intended gesture is held, given that the rest of the components are functional. Additionally, if the micro controller handling the LED's recognizes that it is unable to communicate with the micro controller handling data from the IMU's, or that the data it is receiving is corrupted, the LED's will blink red to indicate to the user that the product is no longer operational. Lastly, in order to clarify to the user how to properly use the product, we could include a brief safety pamphlet to inform the user about the various risks and how to mitigate them.

While the safety risks of assembling this product are minimal, we recognize that there is some form of danger when handling and building electronic components. In order to prevent any injury or harm when assembling this product, we have decided to use electricity resistant gloves.

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