Gesture Based Turn Signaling System

ECE 445 Design Document Spring 2024

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Contents

1 Introduction

1.1 Problem

Cyclists, skateboarders, and scooter riders often face challenges in signaling their intentions to drivers, especially in low-light conditions. According to the CDC, 1,000 cyclists die and 130,000 are injured every year on the road in the United States [1]. These numbers don't include other riders sharing the road on things like skateboards and scooters. There are many interventions in place to prevent these accidents, such as fluorescent or retro-reflective clothing, or active lighting on the bicycle (required by law in most states) [1], but the traditional method of using hand signals is not always visible or practical, particularly at night or during adverse weather conditions. This lack of clear communication can lead to dangerous situations on the road, as other motorists may fail to recognize the cyclist's intended maneuvers, or if an accident occurs.

1.2 Solution

To address this issue, we propose the development of a gesture recognition-based turn signaling system for cyclists and scooter riders. This system will utilize a combination of sensors, such as accelerometers and gyroscopes, integrated into a wearable like a jacket. Then we process the sensor data to identify specific arm gestures made by the rider and activate corresponding LED signals. For example, if the rider extends their arm straight to the left, the left turn signal is activated, or if the rider indicates a stop, then the brake light is activated, and so on. Additionally, the sensors will be able to detect when the rider has had an accident or a crash, and activate a hazard signal.

We propose placing an IMU above (or below depending on how hard it is to differentiate between movements) the elbow on each arm of the wearable. The microprocessor will then receive and process the data from the IMU, determining what kind of movement has been made. Then, depending on the movement, it will output a specific signal to the LEDs to display on the back and arms of the wearable.

1.3 Visual Aid

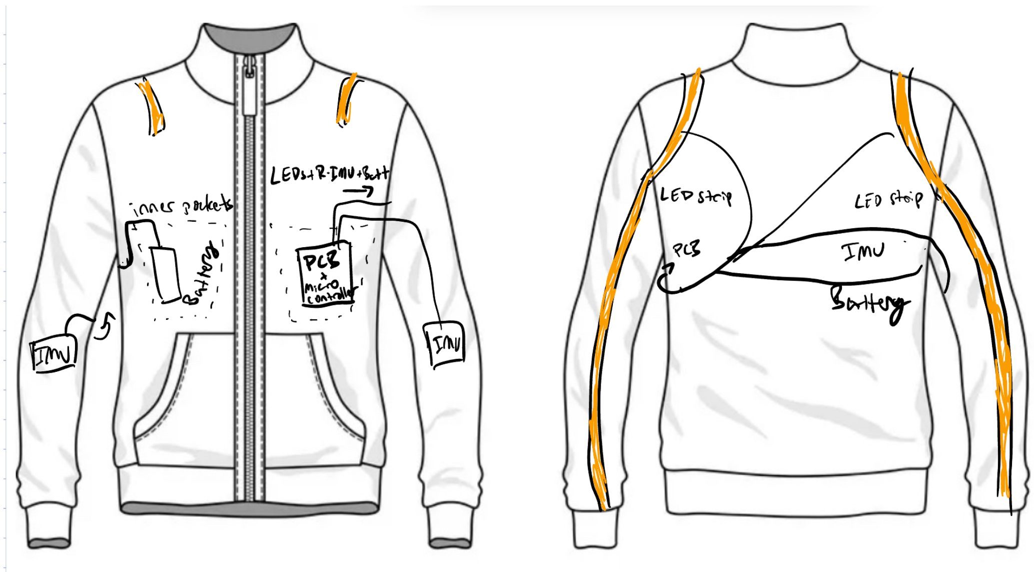

Figure 1: Visual Aid mockup of the wearable [2]

1.4 High Level Requirements

1. The device should be able to correctly detect predefined arm gestures (raising right/left arm for turn signals, forearm down for slowing down) with a minimum accuracy of 90%.

2. The device should be able to correctly map the arm gestures into the different indications on the LEDs. The turn signal will be indicated by either the left or right side LED flashing orange, while the brake/slow down signal will be indicated by all LEDs turning red. A crash or accident will activate the hazard light, indicated by all LEDs flashing red.

3. The turn signals, brake lights, and hazard signals should all be visible and easily identifiable from a distance of at least 250 feet to ensure that they are clearly visible at both day and night.

2 Design

2.1 Block Diagram

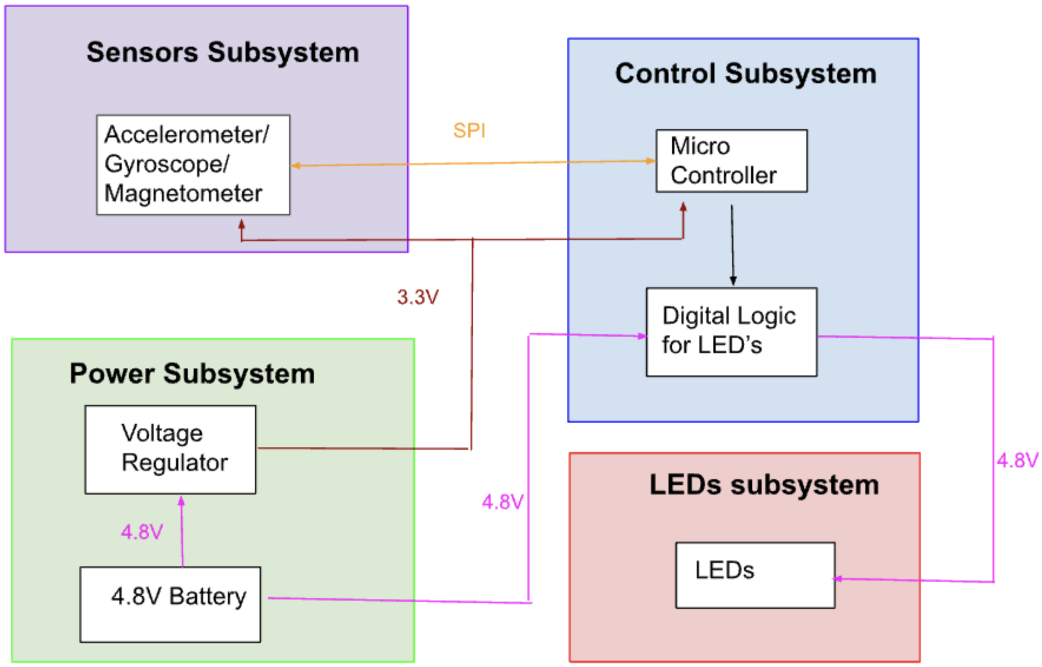

Figure 2: Block Diagram of the system

2.2 Physical Design

Tentative plan for physical design: For the LEDs, we can attach velcro strips at the wrist, elbow, back shoulder, and upper chest areas (both left and right sides), and attach the LED strip along the velcro strips. For the IMUs, place them into small drawstring bags and attach velcro to the outside of the bag and to the inner part of the jacket sleeve near the wrists. The velcro will allow for easier removability for the electronics to aid in debugging as well as for the user to be able to wash the jacket. The PCB and battery can be placed in the inner jacket pockets. For the wiring, we will be physically wiring the LEDs and IMU to the PCB through the inner part of the jacket, making a hole in the front upper chest area to route the LED wires from the outside to the inside to where the PCB will be placed.

2.3 Subsystem Requirements and Verifications

2.3.1 Control Unit

The control unit to be able to receive data through the SPI protocol from the sensors and analyze the data in order to route the 4.8V from the battery to power the LEDs. The data will consist of acceleration, rotational, and magnetic orientation data from the 9 degrees of freedom (9DoF) IMU. The PCB will contain the microcontroller, power the sensor suite, and contain digital logic to control the LEDs. We will use the ESP32 microcontroller [3] to process the data from the sensors and output the correct signals to the LEDs. To turn the LEDs on and off via software, we will add transistors [4] to the PCB, so that the microcontroller can control the power to the LEDs. The control unit will also use software (to be determined and tested) to filter the noise. This data will then be analyzed by the ESP32 to identify the gesture made by the user. This information will then be used to control the LED subsystem.

Table 1: Control Unit Subsystem Requirements and Verification

Requirements	Verification
• Must be able to communicate with the sensors and LEDs through the PCB – Must be able to output 4.8±0.3V to the LEDs – The accelerometer must be able to detect acceleration within ±1m/s. – The magnetometer must be able to detect North. – The gyroscope must be able to detect angular rate within ±15 dps. • Must be able to determine the correct turn signal from the IMU • Must be able to turn on the LEDs based on the corresponding turn signal – Turn left: Must be able to flicker the left LED – Turn right: Must be able to flicker the right LED – Slow down: Must be able to turn on both LEDs – Hazard: Must be able to flicker both LEDs	• Connect the IMU to the ESP32 such that the ESP32 can print the IMU acceleration readings from the accelerometer, gauss reading from the magnetometer, and the angular rate readings from the gyroscope. Drop 3 times (once for each x, y, z axis), and verify that the acceleration is g±5m/s. Point the IMU in different directions and verify that the gauss peaks when pointing North. Spin the IMU using a motor and verify that the angular rate readings match the dps of the motor ±20 dps. • Using the IMU imitate the motion of each of the arm gestures and print out the detected turn signal using the software of the ESP32. Verify if the correct turn signal is displayed on the LED • Move the IMU at a constant velocity and stop quickly (simulate a crash) and verify that the hazard signal is activated through the ESP32 software.

2.3.2 Power Subsystem

We will use a 4.8V rechargeable battery (Li-Ion or LiPo) to power the components, 4.8V for the LEDs, and use a voltage regulator [5] to power the microcontroller and sensors at 3.3V. The Power subsystem should be able to output 4.8V through the control unit to power the LEDs, as well as output 3.3V to power the Control and Sensors subsystems.

Table 2: Power Subsystem Requirements and Verification

Requirements	Verification
• Must be able to supply 3.3±0.3V to the IMUs and the ESP32 • Must be able to supply 4.8±0.3V to the LEDs • The temperature of the battery should stay below 50 C during operation	• The battery will be connected to the voltage regulator and a multimeter will be used to verify that the voltage output by one of the voltage regulators is 3.3±0.3V • To use the multimeter, the positive lead will be connected to the output of the voltage regulator and the negative lead will be connected to the ground of the voltage regulator • Measure the temperature using a thermometer during operation and ensure it is below 50 C

2.3.3 Sensor Subsystem

For the sensors, we will use a 3.3V 9dof IMU (accelerometer, gyroscope, magnetometer) [6] for each arm, and use the combined data from both to determine the nature of the motion. In an accident for example, the acceleration will spike, indicating an accident. To distinguish between the other signals, we will use the gyroscope to determine the angle of the gesture. The IMUs will be powered directly by the power subsystem through a voltage regulator to step the voltage down to 3.3V. The sensors will communicate with the ESP32 microcontroller through SPI for data transfer. The sensor subsystem should contain an IMU (accelerometer, gyroscope, and magnetometer) for each arm, read and controlled by the ESP32 microcontroller via an SPI signal. The data should contain acceleration, rotational, and cardinal direction data and should be filtered properly so as to not miss vital information and not cause false signals. The IMUs will be powered by a 3.3V input via the Power Subsystem.

Table 3: Sensor Subsystem Requirements and Verification

Requirements	Verification
• The accelerometer must be able to detect acceleration within ±1m/s. • The magnetometer must be able to detect North. • The gyroscope must be able to detect angular rate within ±15 dps.	• Connect the IMU to the ESP32 such that the ESP32 can print the IMU acceleration readings from the accelerometer. Drop 3 times (once for each x, y, z, axis), and verify that the acceleration is g±5m/s • Connect the IMU to the ESP32 such that the ESP32 can print the IMU gauss reading from the magnetometer. Point the IMU in different directions and verify that the gauss peaks when pointing North. • Connect the IMU to the ESP32 such that the ESP32 can print the IMU angular rate readings from the gyroscope. Spin the IMU using a motor and verify that the angular rate readings match the dps of the motor ±20 dps.

2.3.4 LED Subsystem

The LED subsystem should be able to turn on the LEDs when powered by a 4.8V input from the control/power subsystems. We will use 2 LED strips with a length of 80 cm each. The strips will start from the upper chest toward the upper back, then it will go towards the wrist, refer to the visual aid for clarifications.

Table 4: LED Subsystem Requirements and Verification

Requirements	Verification
• Must be able to turn on and off given a 4.8V input. • Must be bright enough for drivers to see from 250ft.	• Connect the LEDs in series with a switch and 4.8V power source and verify that the LEDs turn on. • Walk 250 ft away from the LEDs while they are on and check that they are visible

2.4 Tolerance Analysis

We will be using several components operating at 3.3V and a 4.8V battery that allows recharging. Therefore we need to use a voltage regulator to step down the voltage for the sensors and the ESP32. Considering that our product is a wearable, it is important that the component, specifically the linear regulator, doesn't get too hot. We can calculate the change in temperature of the linear regulator by first calculating the power dissipated using $I_{\text{out}}(V_{\text{in}} - V_{\text{out}})$ and multiplying it by the thermal resistance of the linear regulator (Θ_{jc}).

ESP32 worst case current draw: 355 mA

2 IMUs, current draw for each: 4.6 mA

Total current draw: 364.2 mA

Assumed ambient temperature: 25°C

$$\Delta T = I_{\text{out}}(V_{\text{in}} - V_{\text{out}})(\Theta_{\text{jc}}) = 0.36 \times (4.8 - 3.3) \times 5 = 2.7°\text{C}$$

$$\text{Final Temperature} = \Delta T + \text{Ambient Temperature} = 27.7°\text{C}$$

The temperature rise is well within the operating range of the voltage regulator as well as not too warm for the user, so we can use it for our design.

3 Cost and Schedule

3.1 Cost

The total cost of parts will be approximately $141.60 and the expected labor costs are calculated as $\$40/hrs * 2.5 * 60hrs = \$6,000$. This will be applied to all 3 team members so the total labor cost is $\$6,000 * 3 = \$18,000$. This comes out to a total cost of $\$18,141.60$.

Description	Manufacturer	Quantity	Price/unit	Total Price	Link
Jacket	Reebok	1	20.00	20.00	Link
velcro strips	VELCRO Brand	1	20.00	20.00	Link
ESP32	Espressif Systems	1	7.69	7.69	Link
LED strips	Aclorol	2	5.99	11.98	Link
Battery	elxjar	1	24.99	24.99	Link
Voltage Regulator	STMicroElectronics	1	6.95	6.95	Link
IMU breakout board	Adafruit	2	20.00	40.00	Link
Expected Cost of Minor Components (Resistors, Capacitors, etc.)	N/A	N/A	N/A	10.00	
Components Total	N/A	N/A	N/A	141.60	
Labor	N/A	3	40.00	18 000.00	
Total	N/A	N/A	N/A	18 141.60	

3.2 Schedule

Week	Goal	Member
2/26	Design initial PCB that is breadboard compatible to test using the ESP and IMU without the breakout and dev boards	Everyone
	Order necessary parts for prototyping	Sultan
	Begin testing IMU and ESP compatibility using the breakout board and dev board	Kaylan & Edan
3/4	Start PCB design	Everyone
	Use initial PCB design to Connect IMU, ESP, and LED's	Kaylan & Sultan
	Order components for Power subsystem	Edan
	Initial software design	Edan
	3/5 PCB ORDER ROUND 1	Everyone
3/11	Spring Break	Everyone
3/18	Improve initial PCB design to design a new PCB integrating the IMU, ESP, and LED's. **Finish PCB design**	Everyone
	Order new parts if necessary	Kaylan
	Test power subsystem with breadboard	Sultan
	Complete software design	Edan
	3/19 PCB ORDER ROUND 2	Everyone
3/25	Integrate power subsystem into new complete PCB design	Sultan
	Revisions to PCB design	Kaylan
	Revisions to software	Edan
	3/26 PCB ORDER ROUND 3	Everyone
4/1	Fully assemble device and integrate with jacket	Everyone
	Revisions to PCB design if needed	Kaylan
	Revisions to software if needed	Edan
	4/2 PCB ORDER ROUND 4	Everyone
4/8	Leeway week - something is bound to go wrong or get delayed	Everyone
	4/9 PCB ORDER ROUND 5	Everyone
4/15	Mock Demos!	Everyone

Figure 3: Schedule of the project

4 Ethics and Safety

4.1 Ethical Considerations

The biggest concern as it relates to ethics and safety for this project is with regard to the safety of the user and those on the road around the user. Under the IEEE code of ethics (Code I1), we are required to prioritize the safety of the public [7]. If the wearable isn't user friendly enough, or restricts any movements, this can lead to potentially catastrophic accidents. We can solve this by integrating the electronics out of the way of the user, such as in the inner pockets of the jacket (for the PCB and battery), and providing ample slack in the wires throughout. This will allow the user to move more naturally. Another concern might be the privacy of the user [7] because we will be collecting and processing data constantly during a ride/commute. We can limit the data collection to IMU data, so that nothing personally identifiable is collected, as well as deleting any data past a certain period of time.

4.2 Safety Considerations

We have to consider the brightness of the LEDs, and if they can be distracting to other drivers and pedestrians. Having bright LEDs can be beneficial for low light or adverse conditions, but can also be harmful if they dazzle other drivers, impairing their vision. There aren't any safety regulatory requirements for LEDs for bicycles relating to the brightness of the lights, so we make sure we are following the vehicle regulations for turn signals. [8] There are also consumer product safety standards that we need to follow for wearable technology, such as those related to electronics devices and battery safety. It is also important to note that wearing a battery is always dangerous. Because of this we will be following the guidelines on battery safety outlined by UIUC [9]. In addition, we verified in our tolerance analysis that the linear regulators will not get too hot to ensure the safety of the users.

References

[1] Centers for Disease Control and Prevention, "Bicycle Safety," 2024, [Online; accessed 21-February-2024]. [Online]. Available: https://www.cdc.gov/transportationsafety/bicycle/index.html

[2] VectorStock, "Front back and side views blank jacket Royalty Free Vector," 2024, [Online; accessed 21-February-2024]. [Online]. Available: https://www.vectorstock.com/royalty-free-vector/front-back-and-side-views-blank-jacket-vector-4239549

[3] *ESP32 Datasheet*, Espressif Systems, 2016, accessed: Feb. 15, 2024. [Online]. Available: https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf

[4] *VN10K: N-Channel Enhancement-Mode Vertical DMOS FET*, Microchip Technology, 2021, accessed: Feb. 15, 2024. [Online]. Available: https://ww1.microchip.com/downloads/en/DeviceDoc/VN10K-N-Channel-Enhancement-Mode-Vertical-DMOS-FET-Data-Sheet-20005983A.pdf

[5] Texas Instruments, *LM317 3-Terminal Adjustable Regulator*, 2023, accessed: Feb. 22, 2024. [Online]. Available: https://www.ti.com/lit/ds/slvs044y/slvs044y.pdf

[6] *LSM9DS1: iNEMO inertial module: always-on 3D accelerometer and 3D gyroscope*, STMicroelectronics, Geneva, Switzerland, 2015, rev 4. [Online]. Available: https://www.st.com/resource/en/datasheet/lsm9ds1.pdf

[7] Institute of Electrical and Electronics Engineers (IEEE), "IEEE Code of Ethics," https://www.ieee.org/about/corporate/governance/p7-8.html, 2024, accessed: Feb. 15, 2024.

[8] Legal Information Institute, "49 cfr § 571.108 - standard no. 108; lamps, reflective devices, and associated equipment." https://www.law.cornell.edu/cfr/text/49/571.108, 2023, accessed: Feb. 19, 2024.

[9] Division of Research Safety, University of Illinois at Urbana-Champaign, "Battery Safety," https://drs.illinois.edu/Page/SafetyLibrary/BatterySafety, 2023, [Online; accessed 22-February-2024].