Gesture Based Turn Signaling System

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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. 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

1.4 High Level Requirements

1. The device should be able to maintain full functionality for at least 1 hour under standard operating conditions. We define standard operating conditions as continuous use at an ambient temperature of 22°C.

2. The device should correctly detect and interpret predefined arm gestures (right/left signal, slowing down, and crash detection) with a minimum accuracy of 90%. Accuracy will be measured as a percentage of correctly identified gestures performed under a controlled environment.

3. The LEDs should be visible from a distance of at least 250 feet in daylight conditions (ex. clear skies at noon) to ensure that they are clearly visible at both day and night.

2 Design

2.1 Block Diagram

2.2 Physical Design

2.3 Subsystem Requirements and Verifications

2.3.1 Control Unit

We will design our PCB and microcontroller to be able to receive data through SPI from the sensors, analyze the data, and display the correct signal on 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 [1] to process the data from the sensors and output the correct signals to the LEDs.

The control unit should be able to receive SPI data from the sensor subsystem and use the ESP32 microcontroller to analyze it in order to route the 5V from the battery to power the LEDs. To control the LEDs, we will add transistors [2] to the PCB.

Requirements:

- Must be able to communicate with the sensors and LEDs through the PCB
- Must be able to properly filter out noise from the sensor data
- Must be able to determine the correct movements/accident from the sensor data

Verification:

- The control unit will be tested by connecting the sensors and LEDs to the PCB and testing the signals. The signals will be tested by moving the sensors in the correct manner and verifying that the LEDs light up correctly.

2.3.2 Power Subsystem

We will use a 5V rechargeable battery (Li-Ion or LiPo) to power the components, 5V for the LEDs, and use a voltage regulator [3] to power the microcontroller and sensors at 3.3V. We can place the battery in an inner pocket of the wearable, making it easy to wire it to all parts.

The Power subsystem should be able to output 5V through the control unit to power the LEDs, as well as output 3.3V to power the Control and Sensors subsystems.

Requirement:

- Supply sufficient 3.3V-5V power to the other components and subsystems.

Verification:

- The power will be turned on and a multimeter will be used to verify the correct voltage is supplied to all the separate components.

2.3.3 Sensor Subsystem

For the sensors, we will use a 3.3V 9dof IMU (accelerometer, gyroscope, magnetometer) [4] 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.

Requirement:

- Must be able to constantly communicate with the ESP32 throughout a power cycle (1 hour).

Verification:

- Connect the sensors to the ESP32 and verify through software that the ESP32 is receiving all the correct information at a reasonably fast rate.

2.3.4 LED Subsystem

We will use 5V LED strips placed on the back and arms of the wearable to display the information. The LEDs will be arranged on the back of the arms and over the shoulder from the shoulder blade to the upper chest area (for front visibility).

The LED subsystem should be able to turn on the LEDs when powered by a 5V input from the control/power subsystems.

Requirement:

- Must be able to turn on and off when instructed to by the microcontroller.
- Must be bright enough for drivers to see at night at a reasonable distance (250 ft).
- Must be able to display different colors for turn signals/hazards and braking.

Verification:

- Connect the LEDs to the PCB and use software to turn them on and off.
- When powered by the power subsystem, walk 250 ft away and verify that they are visible.
- Modify the RGB values of the LEDs through software on the ESP32.

2.4 Tolerance Analysis

We will be using several components operating at 3.3V and a 5V battery that allows recharging. Therefore we need to use a voltage regulator to step down the voltage for the sensors and the ESP32.

ESP32 worst case current draw: 240 mA

2 IMUs, current draw for each: 4.6 mA

$$\begin{aligned}
\text{Input power} &= V_{\text{in}} \times I_{\text{load}} = 5V \times (0.24A + 2 \times 4.6mA) \\
\text{Output power} &= V_{\text{out}} \times I_{\text{load}} = 3.3V \times (240mA + 2 \times 4.6mA) \\
\text{Power dissipated} &= P_{\text{in}} - P_{\text{out}} \quad \text{(worst case)} \\
\text{Temp Rise} &= P_{\text{diss}} \times R_{\text{th}} = 19.9\,{}^{\circ}C \\
\text{Estimated total temp} &= 25 + 19.9 = 44.9\,{}^{\circ}C
\end{aligned}$$

The temperature rise is well within the operating range of the voltage regulator, so we can use it for our design.

Additionally we need to make sure we aren't overloading the battery which can cause overheating. We will need to be careful to not cause the battery or the voltage regulator to overheat. Overheating would run the risk of damaging the rider, as well as affecting the rest of the parts negatively.

LEDs current: $2A$ total

ESP32 and IMUs: $240mA + 2 \times 4.6mA$

$$\begin{aligned}
\text{Battery Efficiency} &= 90\% \\
P_{\text{total}} &= V \times I = 5(2A + 240mA + 2 \times 4.6mA) = 11.246W \\
P_{\text{loss}} &= \frac{P_{\text{total}}}{\text{Efficiency}} - P_{\text{total}} = 11.246W - 11.246W = 1.25W \\
R_{\text{th}} &= 20\,^{\circ}C/W \\
\text{Temp rise} &= P_{\text{loss}} \times R_{\text{th}} = 25\,^{\circ}C \\
\text{Total temp} &= 25 + 25 = 50\,^{\circ}C
\end{aligned}$$

3 Cost and Schedule

3.1 Cost

3.2 Schedule

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, we are required to prioritize the safety of the safety of the public [5]. 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 [5] 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. [6] 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.

References

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