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Project No.15

SMART HELMET WITH LIGHT INDICATORS FOR BRAKES & TURNS

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Abstract

In our project proposal, we are addressing the challenge of motorcycle safety by attempting to increase their visibility to other vehicles. This is done by incorporating turn and brake signals on helmets, which being required in many places by law, would be both physically as well as legally positioned to serve better than existing turn lights. We outline the usage of components required for this project, the wireless communication between light sensors and microcontrollers, as well as ethics and safety guidelines we are abiding by for our project.

Contents

1. Introduction

Motorcycle riders account for 14% of all traffic facilities, despite the fact only 3% of all registered vehicles are motorcycles, and “The number of motorcyclist fatalities in 2021 increased by 8 percent from 2020, from 5,506 to 5,932.” [1] According to the National Highway Traffic Safety Administration (NHTSA) of the United States Department of Transportation, “More than other vehicle drivers, motorcyclists must remain visible at all times, and anticipate what might happen.” We want to address this safety problem. Lane splitting is a common practice endorsed by American Motorcyclist Association, wherein a motorcycle’s narrow width can allow it to pass between lanes of stopped or slow-moving cars on roadways where the lanes are wide enough to offer an adequate gap.

We believe to address all the above, (visibility to other vehicles, aiding lane splitting and reducing fatality) it is essential to remove ambiguity about the motorcyclist’s path and make turn signals and braking more visible.

1.1 Problem

The biggest challenge faced by motorcyclists on roads is their visibility to other vehicles. Left turn crashes due to oncoming traffic being unable to assess their turn intention (turn signals are mostly situated on the back of motorcycles) are exceedingly common. In 2021, 42 percent (1,158) of motorcycles-vehicle collisions were due to the other vehicles turning left while the motorcycles were going straight, passing, or overtaking other vehicles [1]. Furthermore, many countries of the world are still using hand signals to communicate turn intention!

Another instance where turn signals are obviously critical involves the practice of lane splitting, which is legal in 17 US states. Lane splitting involves weaving in and out of traffic lanes to reduce the risk of cars running into the back of the motorcycle in stop-and-go traffic. More states are considering legalizing this practice, which, if carried out with proper training and safety, can help reduce crashes from the back. However, lack of turn signal/braking visibility can make this practice incredibly dangerous.

1.2 Solution

Our solution proposes to increase the visibility of motorcyclists by a simple, yet practical solution: by integrating turn and brake signals onto helmets using strong LED strips. 18 US states make it illegal to ride motorcycles without helmets, and many others require young riders to do so as well, making this a solution that would be enabled by law. As the lights will be visible on the sides as well as the back of the helmet, they will be a lot more difficult to miss or confuse. The helmet will be able to communicate wirelessly with the turn and brake signals in real time, and a combination of light sensors, microcontrollers with Bluetooth modules and LED lights will be used to complete this project.

1.3 Visual Aid

Figure 1: Expected LED placement on helmet.

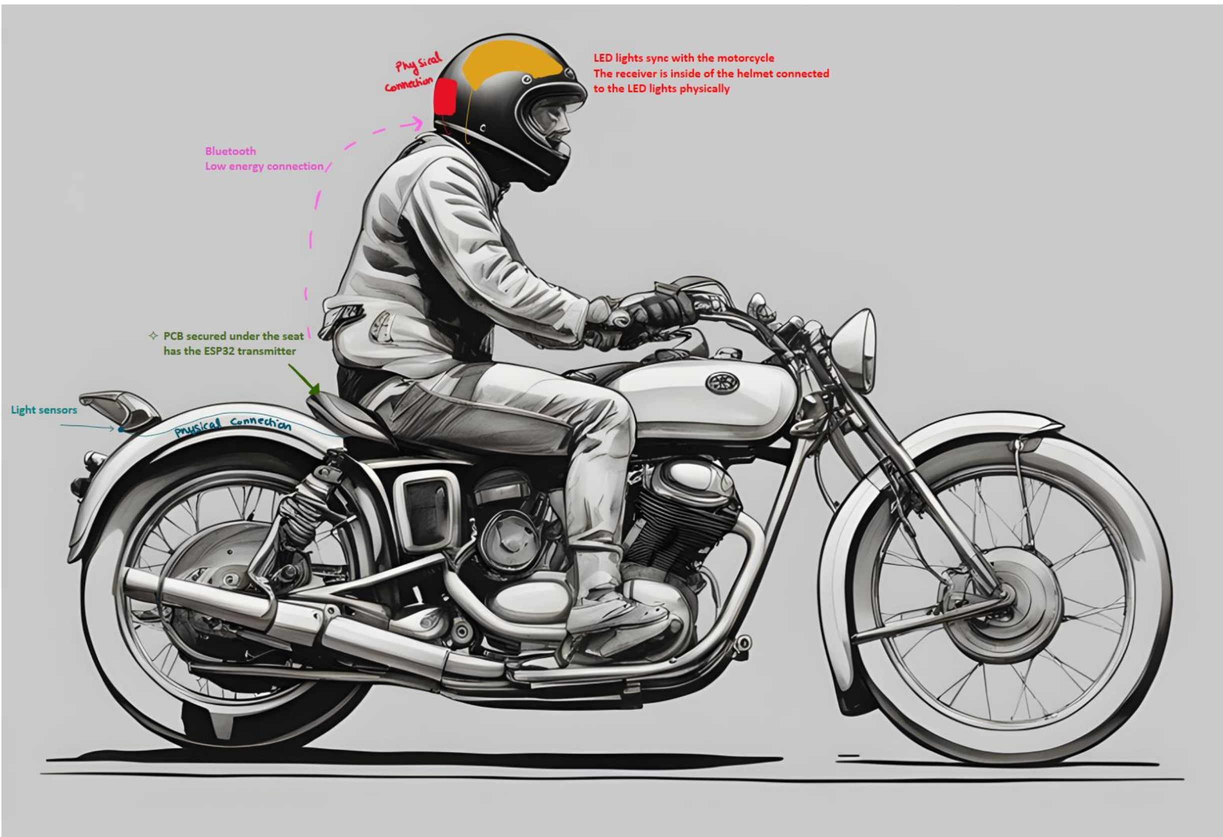

Figure 2: LED and circuitry placement relative to motorcycle

1.4 High-level Requirements

We would expect our project to fulfill the following high-level requirements:

1. When the motorcycle's right turn signal illuminates and blinks, the helmet's right LED should illuminate and blink. The same relationship should apply to the left LED.
2. When the motorcycle applies its brakes and its brake lights illuminate, the helmet's brake light should illuminate. When the brakes are released, the LED should turn off.
3. Latency for the helmet LED lighting up, especially the brake, should be very low, ideally as low as possible to communicate in real time precisely the moment when brakes have been applied. Should not be above 3 seconds.
4. Battery should work for ~ hours and should indicate when the battery is below 20%.

2 Design

2.1 Block Diagram

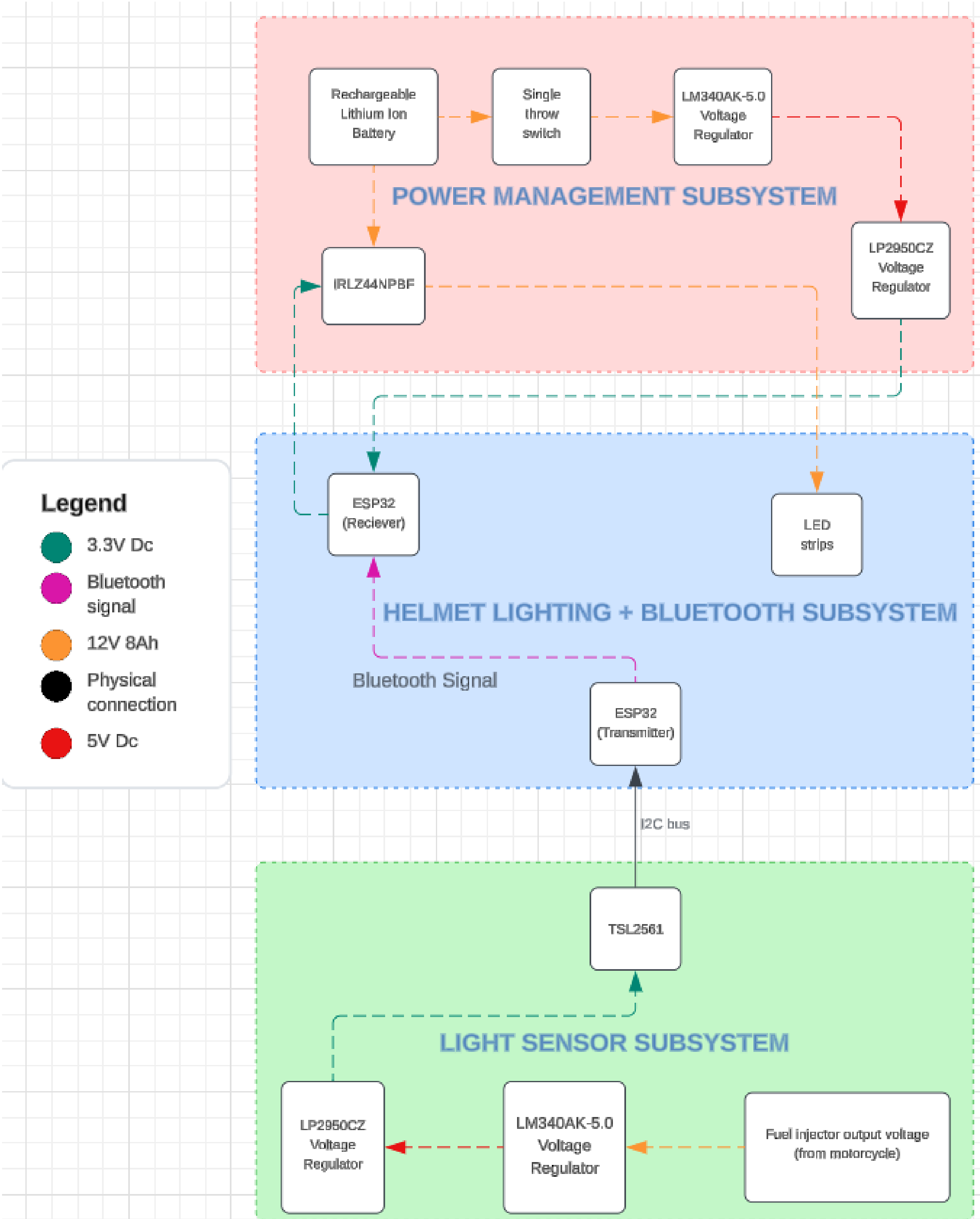

Figure 3: Block Diagram for the lighting system

2.2 Subsystem Overview

2.2.1 SUBSYSTEM 1: LIGHT SENSOR SUBSYSTEM

Light Sensor: Light-to-Digital Sensor TSL2561
Microcontroller: ESP32
External Pull-up resistors
The TSL2561 will communicate via I2C (multi-master, multi-slave) bus with ESP32, and will allow us to read the light intensity data from the turn signal. This will be affixed to our PCB in the motorcycle itself (can be accommodated under the seat discreetly).

2.2.2 SUBSYSTEM 2: BLUETOOTH SUBSYSTEM - HELMET & MOTORCYCLE COMMUNICATION

The ESP32 is also used for its Bluetooth communication capabilities, which eliminates the need for an additional Bluetooth module. We plan to use BLE (Bluetooth Low Energy) to keep our power usage efficient. It will be used both as a transmitter and a receiver. One will be affixed to our main circuit, and the other will be fixed to the helmet to transmit light sensor data.

2.2.3 SUBSYSTEM 3: HELMET LIGHTING SUBSYSTEM

The Helmet lighting Subsystem will be connected to ESP32 connected in the helmet which would be acting as a receiver from the main circuit connected to the motorcycle. It will turn on the LEDs present in the helmet.

The Turn Signal LEDs will be on the upper side of the helmet so that they don’t obstruct the peripheral view of the rider by being too bright. Most road accidents relating to lights on the motorcycle are due to left turns, so we made sure that the LED would be seen from the front as well. The brake light on the other hand only needs to be seen from the back.

The helmet will be a bigger size than normal and will have extra padding so that the power system and Bluetooth system are not in direct contact with the rider's head white still being a good fit.

LEDs: Red and amber LEDs to be affixed to the helmet to be compliant with Illinois law. To avoid compromising the structural integrity of the helmet, we will be doing it using strong adhesive/Velcro strips.

2.2.4 SUBSYSTEM 4: POWER MANAGEMENT SUBSYSTEM

For the components connected to the motorcycle they will be connected to the Fuel Injector Output Voltage which only supplies power when the motorcycle is on, so the system should not drain the power when the motorcycle is not in use. (For simplicity purposes initially, we will be using a separate battery pack for the system connected to the motorcycle and this may be a stretch goal.) Rechargeable batteries will be present inside the helmet to power up the ESP and the LEDs.

For the motorcycle battery connection:
LM7805 Voltage Regulator - step down the voltage from 12V (from motorcycle) to 5V
LM117-3.3 Voltage regulator – step down voltage from 5V to 3.3v for use with esp32 and tsl2561
AMS1117-1.8 Voltage regulator for use with
Adafruit 1200mAh 3.7V Lithium-Ion Polymer Battery - PLU #258 (to step down voltage from 3.7V to 3.3V)
Battery Managing IC TI BQ76930 - Monitor overcharging of the battery as a safety mechanism.
nMOS power switch - Control power to our LEDs.

Due to the possibility of the battery heating up and to maintain the safety of the helmet the battery pack will be in cased in flame retardant fiberglass bag https://www.amazon.com/Fireproof-Temperature-Resistant-Retardant-Explosion/dp/B0CF9KGNQ7 that would be stitched up to fit the battery pack.

2.3 Subsystem Requirements

2.3.1 SUBSYSTEM 1: LIGHT SENSOR SUBSYSTEM

1. Hardware set-up requirements [2]:

1.1 The power supply lines must be decoupled with a 0.1 µF capacitor placed as close to the device package as possible. This bypass capacitor should have low effective series resistance (ESR) and low effective series inductance (ESI), such as the common ceramic types, which provide a low impedance path to ground at high frequencies to handle transient currents caused by internal logic switching.

1.2 Pull-up resistors are required for the SDAH and SCLH lines at a high level, and a separate pull up resistor between 10 kOhm and 100kOhm is required for the interrupt (INT) line.

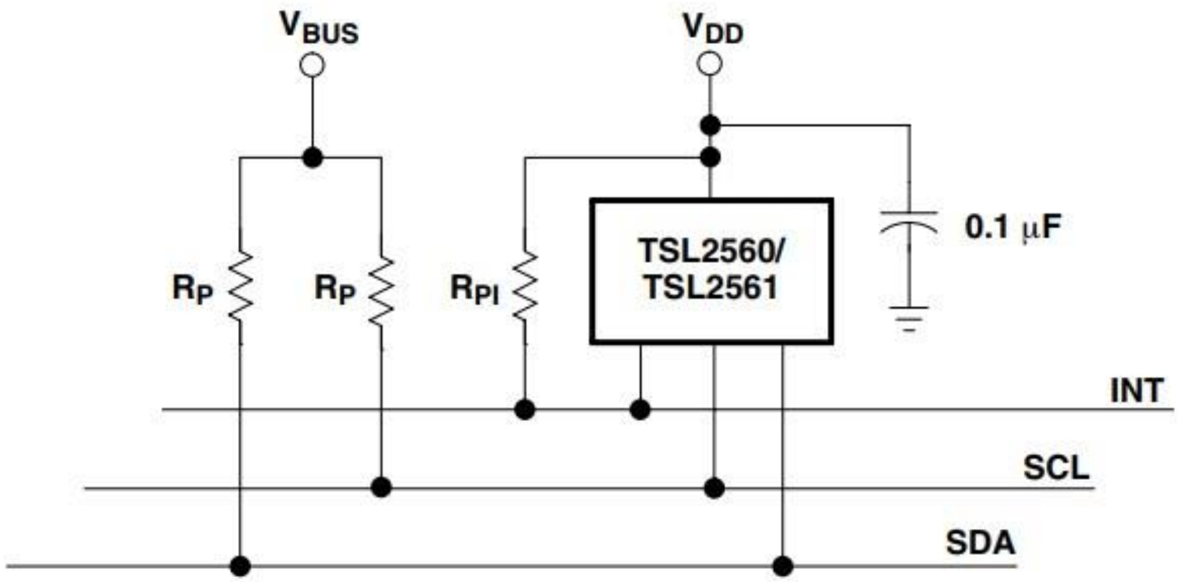

Figure 4: Bus pull-up resistors

2. Sensitivity and Performance requirements:

The sensor should be able to differentiate between ambient light conditions and the motorcycle's turn and brake lights. For this, the integration times and gain settings need to be correctly configured to optimize response for light intensity changes.

3. Communication with ESP32:

The light sensor should be detected by the ESP32 and should periodically obtain a light reading from it, displaying it on the console. One TSL2561 device will be connected to two GPIOs on the ESP32 (I2C SDA and SCL).10 kOhm resistor from each GPIO to the 3.3V supply are connected to act as pull-up resistors.

2.3.2 SUBSYSTEM 2: BLUETOOTH SUBSYSTEM - HELMET & MOTORCYCLE COMMUNICATION

1. The ESP32 must establish a Bluetooth Low Energy connection between the helmet and the motorcycle.

2. The Bluetooth subsystem must reliably transfer light sensor data between the helmet and motorcycle.

3. The Bluetooth system should be able to remain connected during travel

Comprehensive testing scenarios should include pairing, connection initiation, reconnection after disconnection, and handling of potential connection errors or interruptions. Signal strength and range testing must be conducted to guarantee reliable communication under various environmental conditions, such as interference from other devices or obstacles between the motorcycle and the helmet.

Data integrity checks and error correction mechanisms should be implemented to detect and mitigate transmission errors that may occur due to noise or signal degradation. Buffering and packetization techniques can be employed to ensure smooth and uninterrupted transmission of sensor data, even in scenarios where the Bluetooth connection experiences fluctuations in bandwidth or latency.

Robust error handling mechanisms should be in place to handle situations where the light sensor data transmission fails or encounters errors, ensuring that the system can recover gracefully and maintain functionality.

2.3.3 SUBSYSTEM 3: HELMET LIGHTING SUBSYSTEM

1. Turn signal LEDs must be visible from the front & back and the brake light LED must be visible from the back

2. LEDs must be securely fixed to the helmet

3. The LED light must not restrict the motorcyclist vision

4. The LEDs should be visible in bright sunlight.

The positioning of the turn signal LEDs on the upper side of the helmet, away from the rider's direct line of sight, prevents distraction and maintains the rider's focus on the road ahead. Similarly, ensuring that the brake light LED is visible from the back alerts following vehicles to the rider's intention to decelerate or stop, reducing the risk of rear-end collisions.

The secure fixation of LEDs to the helmet is crucial to prevent detachment or dislodgment during normal riding conditions, which could pose a safety hazard to the rider and other road users. The use of strong adhesive or Velcro strips provides a reliable method for affixing the LEDs to the helmet without compromising its structural integrity or compromising safety standards. We will also do rigorous testing procedures that should be implemented to assess the durability and stability of the attachment mechanism under various environmental conditions, including exposure to vibrations, wind forces, and temperature fluctuations.

For the 4th requirement, according to sources, "Legally required for daytime running lights on motorcycles is a brightness of minimum 400 candelas and a maximum of 1200 candelas." The following table illustrates the relationship between legal limits on brightness (in Candela), motorcycle manufacturing constraints (lights in lux)[3] and the resultant distances they can be visible from.

We will test our subsystem to make sure that the LEDs follow all of these expected brightness levels during daytime. [15]

Brightness (in Candelas)	Distance (in feet)	Illuminance (in Lux)
400	6.9	90
1200	12	90
400	11	35
1200	19	35

2.3.4 SUBSYSTEM 4: POWER MANAGEMENT SUBSYSTEM

1. Components directly connected with the motorcycle must receive power from the fuel injector voltage output only when the motorcycle is on

2. The system should only use/drain when power when the motorcycle is on

2.4 Tolerance Analysis

1. For the light sensor TSL2561, the two main configurations that can be sources of errors are the style of interrupts chosen and the lux value outputted by the sensor.

   1.1 Interrupt styles are determined by the INTR field in the Interrupt Register and the primary purpose is to detect a "meaningful" change in intensity. This can be defined both in terms of light intensity and time, or persistence, of that change in intensity. We can define a threshold above and below current light level or specify a number of conversion cycles for which a light intensity exceeding either interrupt threshold must persist before actually generating an interrupt. This can be used to prevent transient changes in light intensity from generating an unwanted interrupt. This value can range from 1 (interrupt occurs immediately whenever either threshold is exceeded) to

15 (15 consecutive conversions must result in values outside the interrupt window for an interrupt to be generated).

For e.g., if N is equal to 10 and the integration time is 402 ms, then an interrupt will not be generated unless the light level persists for more than 4 seconds outside the threshold.

1.2 As mentioned in subsystem requirements, the integration time and gain settings directly impact the accuracy of light intensity reading. These are fixed using the TIMING register.
INTEG FIELD VALUE "00": Integration time is 13.7 ms with a scale factor of 0.034.
INTEG FIELD VALUE "01": Integration time is 101 ms with a scale factor of 0.252.
INTEG FIELD VALUE "10": Integration time is 402 ms with a scale factor of 1.
INTEG FIELD VALUE "11": Not applicable (N/A), as this setting is used for manual timing control and stops the integration cycle when writing a 0.
These settings allow for adjustment of the sensor's sensitivity and response time to changes in light intensity. The scale factor adjusts the sensitivity of the sensor to light, with a higher scale factor (closer to 1) providing greater sensitivity.

The gain setting (low gain at 1× or high gain at 16×) directly influences the sensor's light sensitivity. High gain settings can allow for better detection in low-light conditions but may lead to saturation under bright conditions. The chosen integration time and gain setting must be matched to the expected light levels for accurate light intensity measurements.

Motorcycle lights are generally between 35 and 90 lux [3], and for this range we will test with low gain (1x) first, especially in a moderately lit environment. If the sensor fails to differentiate light levels adequately at this setting, we will switch to high gain (16x).

2. In microcontrollers, floating point operations are often not supported, or have poor performance, so the lux calculation must be done without floating point operations. Since floating point has been removed, scaling must be performed prior to calculating illuminance if the integration time is not 402 ms and/or if the gain is not 16. This is explained in detail in the TSL2561 software integration portion of the datasheet.

3. **For the TSL2561 light sensor:**
Supply Current: Active mode 0.24 to 0.6 mA, Power-down mode 3.2 to 15 µA.
Voltage: Output low voltage at 3 mA sink current is 0 to 0.4 V and at 6 mA sink current is 0 to 0.6 V.
Leakage Current: -5 to 5 µA.

For the ESP32 microcontroller:
Input Voltage (VIH/VIL): High-level input voltage is 0.75 times the supply voltage to the supply voltage plus 0.3 V. Low-level input voltage is -0.3 V to 0.25 times the supply voltage. [4]
Output Voltage (VOH/VOL): High-level output voltage is 0.8 times the supply voltage. Low-level output voltage is up to 0.1 times the supply voltage. [4]
Sink Current (IOL): Low-level sink current is up to 28 mA for output drive strength set to the maximum. [4]

4. The ESP32's VIH and VIL levels must match the TSL2561's logic levels for proper communication. Since TSL2561 operates with logic levels based on its supply voltage (2.7V to 3.6V), we will ensure that the ESP32's GPIO pins, when configured for I2C communication work with these levels.
5. Both the ESP32 and TSL2561 have specified operating temperature ranges. The devices' performance, including the accuracy of the TSL2561's (operates between 243 K to 343 K) light measurements and the ESP32's (operates between 233 K to 398 K) [4] processing capability, may vary with temperature.
6. **Heat tolerance analysis:** The main sources of heat dissipation in our project are:

ESP32: The products sealed in moisture barrier bags (MBB) should be stored in a non-condensing atmospheric environment of < 40 °C and 90%RH. The module is rated at the moisture sensitivity level (MSL) of 3.

After unpacking, the module must be soldered within 168 hours with the factory conditions 25 ± 5 °C and 60%RH. If the above conditions are not met, the module needs to be baked.

Voltage Regulators: We will calculate the maximum power dissipation and thermal resistance as such:

$P_{dmax} = (V_{in} – V_{out}) * I_{out} + V_{in} * I_q$

Where P_{dmax}: Maximum Power Dissipation, V_{in}: Input Voltage, Vout: Output Voltage I_{out}: Output Current, I_q: Quiescent Current

We will calculate the thermal resistance (Rt) from the junction to ambient to ensure the junction temperature (Tj) does not exceed the maximum rated junction temperature (Tjmax) using:

Tj = Ta + Pd * Rt, where Ta is ambient temperature

For LM340, Tjmax = 150°C , junction-to-ambient thermal resistance (Rt) is 39°C per watt [12].

LP2950 has a thermal resistance junction-to-ambient (Rt) of 180°C/W for the SOIC-8 package, and the maximum junction temperature (TJ) is +150°C .[11]

Batteries: We are using the Turnigy Graphene Panther 4S 1300mAh 75C LiPo Battery. We will monitor the battery temperature to prevent heating over around 60°C (140°F) which is the maximum recommended temperature for LiPo batteries [14].

3. Ethics and Safety

In developing the smart motorcycle helmet, we recognize that it is important to address ethical & safety considerations during the development and the lifecycle of the product, on and off the road. Throughout our time as students and soon as professional engineers, we will adhere to the ethical principles outlined in both the IEEE and ACM Codes of Ethics. These codes will be the basis of principles in our journey and will guide us through ethical decisions we face. By addressing the following, we are committed to designing and developing a motorcycle helmet that improves rider safety and upholds ethical principles.

3.1 Ethics

3.1.1 User Safety

Our biggest concern is the safety of the helmet user. Our commitment is to design a helmet that creates a safer environment for every motorcycle rider that uses it, without compromising ethical principles. As stated in the IEEE code, we must prioritize public safety in professional activities. Additionally, we also value transparency and will make certain that users are fully informed of all capabilities of the helmet.

3.1.2 Accessibility

Another focus of our agenda focuses on designing an inclusive project that can be used by all motorcycle riders, regardless of technological understanding or physical capabilities. As seen in the IEEE code, there is immense value in promoting diversity and accessibility in all engineering projects.

3.1.3 Professionalism

As a group, we will work to uphold the highest level of professionalism throughout our product's development. We will accurately and honestly communicate our product's capabilities, in line with the principles of integrity in professional practice outlined in the IEEE and ACM codes.

3.2 Safety

3.2.1 Regulation, Durability, & Integration

We will work to make sure the helmet complies with federal safety regulations as outlined by the United States Department of Transportation and with industry standards related to safety. This will involve materials testing and padding implementations to ensure the helmet provides proper protection in case of a crash. We will also adequately integrate the helmet with existing subsystems of the motorcycle to ensure compatibility and reliability of the product. This will culminate in real-world test rides performed by a licensed driver to verify performance.

3.2.2 Product Instruction

We will ensure comprehensive product training to users to ensure proper use of the helmet to mitigate safety concerns related to user error.

References

[1] https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813466.pdf

[2] *https://cdn-shop.adafruit.com/datasheets/TSL2561.pdf*

[3] https://herrmans.eu/news/bike-light-buying-guide-how-many-lumens-or-lux-do-i-need/

[4] https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf

[5] https://www.link-labs.com/blog/bluetooth-vs-bluetooth-low-energy

[6] https://www.ieee.org/content/dam/ieee-org/ieee/web/org/about/corporate/ieee-code-of-ethics.pdf

[7] https://www.acm.org/code-of-ethics

[8] https://randomnerdtutorials.com/esp32-pinout-reference-gpios/

[9] https://grainger.illinois.edu/academics/undergraduate/majors-and-minors/electrical-engineering - :~:text=The average starting salary for,average signing bonus of %249,554.

[10] https://www.picoauto.com/library/automotive-guided-tests/injector-voltage/ - :~:text=The injector is an electromechanical,is switched via the ECM.

[11] https://www.onsemi.com/pdf/datasheet/lp2950-d.pdf

[12] https://download.datasheets.com/pdfs/2013/4/22/5/11/18/625/txn_/manual/6500lm340-n.pdf

[13]https://www.espressif.com/sites/default/files/documentation/esp32_technical_reference_manual_en.pdf#i2c

[14] https://www.jauch.com/blog/en/6-important-parameters-for-the-design-in-of-lithium-polymer-batteries/#:~:text=By%20default%2C%20lithium%20polymer%20cells,prevail%20when%20charging%20the%20cells.

[15] https://www.kellermann-online.com/en/magazin/bright.-ideas/daytime-running-lights-for-motorcycles-simply-explained/