HELMETIQ FINAL REVIEW PRESENTATION

Summer-Fall 2024 Group 8

OUR TEAM

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MOTIVATION

- The NHTSA reports that approximately 45,000 cyclists are involved in accidents annually, with a helmet often being the only protective gear worn.
- We aim to provide enhanced safety features without making the cyclist wear additional equipment.
- Cyclists face significant risks, primarily from motorists rather than their own actions.
- By incorporating adaptive lighting, automatic brake lights, and ride data tracking into a single, cohesive unit enhances both safety and convenience for cyclists.

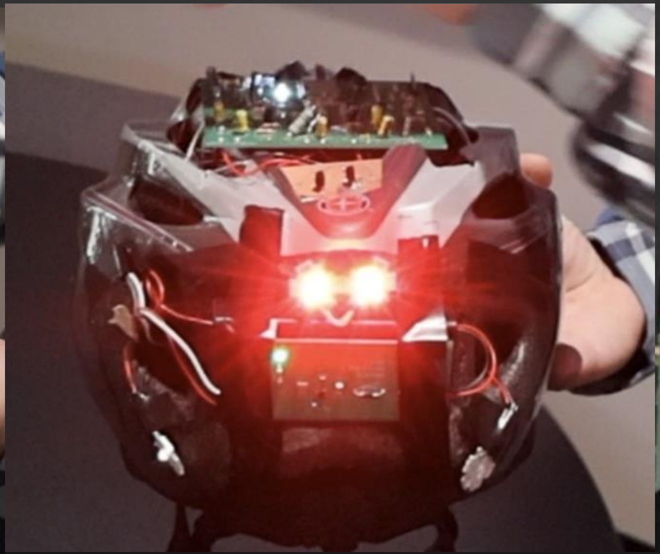
GOALS AND OBJECTIVES

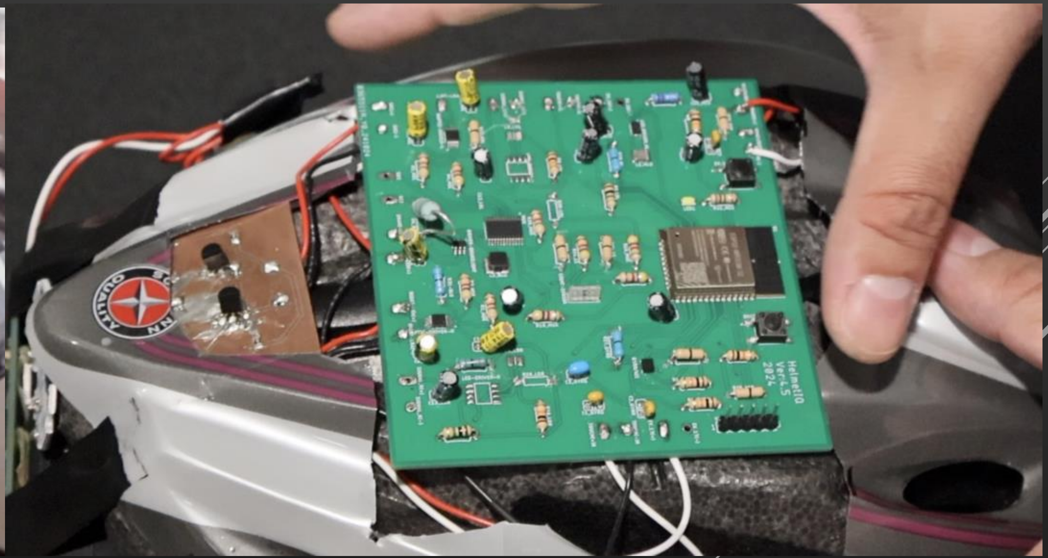
- Goals
  - Design and implement an advanced smart helmet system with multiple integrated sensors for enhanced safety.
- Objectives
  - Creation of a companion app to monitor and control helmet features via wireless communication.
  - The implementation and integration of sensors to calculate and detect if an impact has occurred.
    - *If a collision has occurred, user's emergency contacts will be notified.*
  - Taillights that communicate with an accelerometer to automatically turn on during deceleration and acceleration.
  - Touch-activated turn signals with tactile feedback on the rider's head.

ENGINEERING SPECIFICATIONS

Component(s)	Parameter	Design Specification
Haptic Feedback System	Feedback Time	< 0.5 seconds after pressing capacitive touch sensors
Collision Detection System	Detection Delay	Prompt user on mobile app of a collision within 2 seconds of the helmet signaling a collision
Headlight & Taillight Activation	Activation Delay	Response within 2 seconds of environmental change
On-Helmet Collision Detection	Detection Accuracy	Detect the simulated collision at 90% accuracy
Capacitive Touch Sensors	Sensitivity	Detects 3 to 6 newtons of force
LED Indicators	Brightness	Visible from 50 meters
Battery	Battery Life	2 hours continuous use
Helmet Weight	Weight	Less than 4 kg additional weight
Helmet Enclosure	Durability	Withstands 10 pounds of force
Communication Module (optional)	Range	Maintain connection within 15 meters
Light Sensor	Light Detection	Detects Lux value with in 0.5 seconds
Headlight	Visibility	Visible from 100 meters

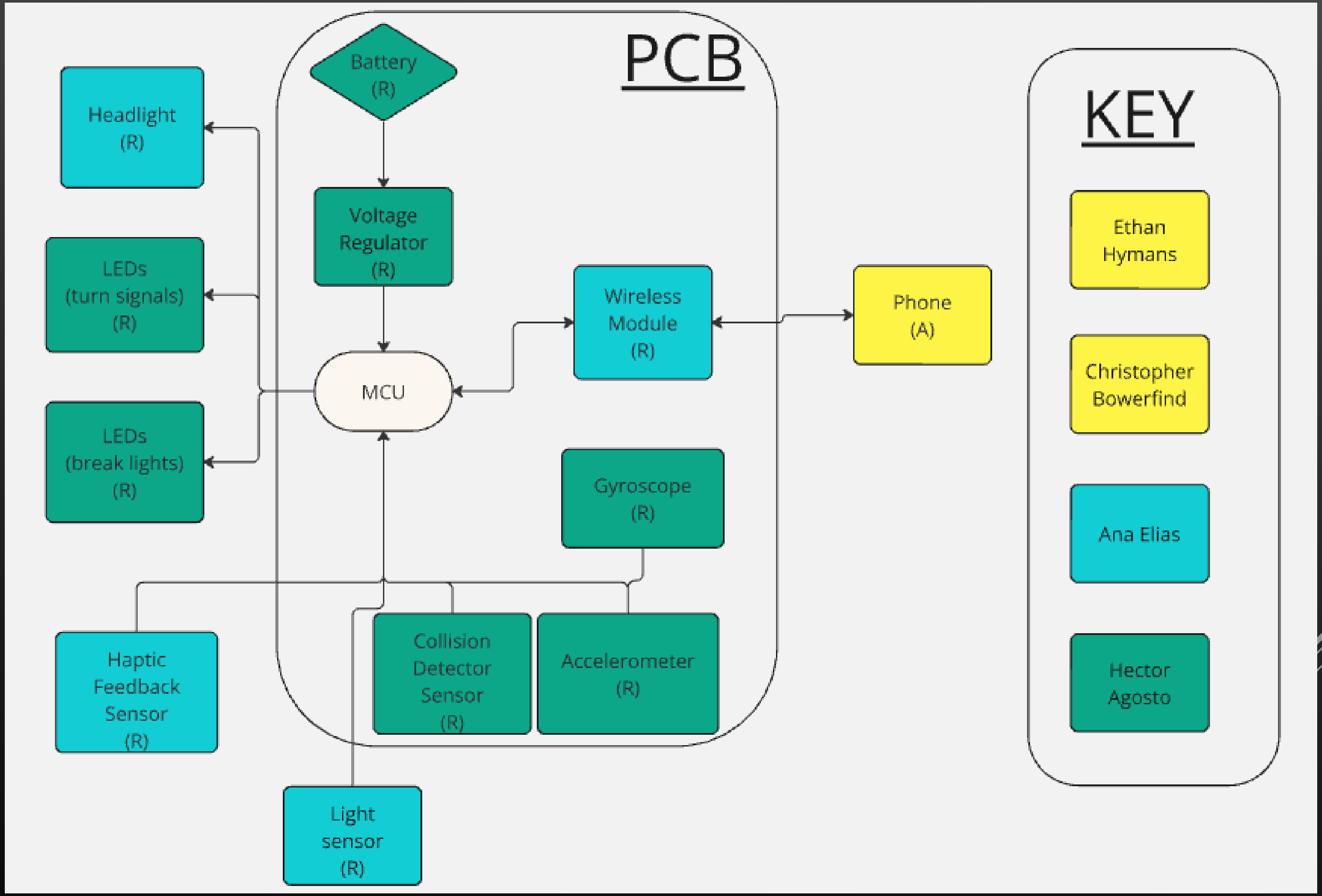
HARDWARE IMPLEMENTATION OVERVIEW





HARDWARE BLOCK DIAGRAM

- Battery – 18560 Li-ion battery cells
- Touch Sensor – TTP223
- Haptic Feedback Sensor – ERM Motor w/DRV2605L Haptic Driver Accelerometer/ Gyroscope – ICM-42670-P



PERIPHERAL SENSORS

- Touch Sensor
  - Uses a capacitive touch sensor to activate the turn signal
- Haptic Feedback Sensor
  - Provides tactile feedback for turn signal activation, alerting the user with minimal distraction
- 3-Axis Accelerometer and Gyroscope
  - Detects sudden impacts and triggers brake lights
  - Used for collision detection and motion tracking
- Light Sensor
  - Adjusts lighting based on outside light condition for intelligent headlight control

TOUCH SENSOR COMPARISON

- Capacitive touch sensors can detect touch through non-conductive surfaces like glass and plastic

Feature	Resistive Touch Sensor	Capacitive Touch Sensor (TTP223)
Operation	Requires physical pressure to detect	Detects light touch via electrical field
Sensitivity	Lower sensitivity, slower response	High sensitivity, quick response
Durability	Prone to wear and tear	Durable, works through protective layers
Accuracy	Less accurate, can misread inputs	Highly accurate, reliable touch sensing
Environmental Performance	Works with gloves, insensitive to moisture	Affected by water but can sense through non-conductive materials
Power Consumption	Higher due to mechanical interaction	Low power consumption
Cost	Generally cheaper	Slightly more expensive

TOUCH SENSOR SELECTION

- Capacitive touch sensors are more responsive and accurate, while resistive touch sensors require physical pressure, leading to slower input
- Capacitive touch sensors can detect touch through non-conductive surfaces like glass and plastic

	Resistive Touch Sensor (DF9-16)	Capacitive Touch Sensor (TTP223)
Operating Voltage	1V	2.5 ~5.5V DC
Thickness	0.4mm	1.35128mm
Trigger Force	20g, triggered when resistance is less than 200kΩ	0-50pF
Response Time	<10ms	60ms at fast mode, 220ms at low power mode @VDD=3V
Activation Time	<0.01s	Initial stable-time of 0.5s after power-on
Weight	1g/0.04oz	1.0 Ounce
Control Method	Pressure	Touch

HAPTIC FEEDBACK COMPARISON

- Vibrotactile feedback is ideal for wearable technology as it can provide subtle but effective feedback

Feature	Eccentric Rotating Mass (ERM) Motors	Linear Resonant Actuator (LRA)	Piezoelectric Actuators
Operation	Spins an unbalanced mass to create vibration	Vibrates a mass along a single axis at resonance frequency	Deforms when voltage is applied, producing vibration
Response Time	Slower (50-100 ms)	Fast (10-20 ms)	Fast (<10 ms)
Power Consumption	Higher	Lower	Low
Vibration Precision	Lower precision	High precision	Very high precision
Durability	Moderate, more mechanical wear	High durability	Fragile (prone to material fatigue)
Size	Larger, bulkier	Compact, lightweight	Compact but delicate
Cost	Low	Moderate	High
Best Use Case	Low-cost devices, simple feedback	Wearables, high precision feedback	Specialized applications (e.g., medical)

HAPTIC FEEDBACK SELECTION

- We selected ERM motors due to its strong, low-frequency vibrations which deliver immediate haptic feedback all while meeting our cost and availability requirements.

ACCELEROMETER/GYROSCOPE COMPARISON

- Multi-axis MEMS gyros offer compactness and simplified calibration, reducing device footprint and complexity.

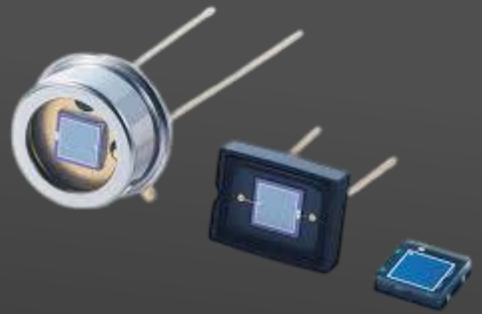
	Vibrating ring	**Multi-Axis**	**Tuning-fork**	**Gimbaled**
Power Consumption	.01mW to 1mW	.02mW to 5mW	.01mW to2mW	1mW to 10mW
Cost	Moderate	Very High	Moderate	High
Bandwidth	Moderate	Variable	Moderate	High
Sensitivity	50 deg/s to 500deg/s	50 deg/s to 2000deg/s	10 deg/s to 1000deg/s	.01 deg/s to 100deg/s
Complexity	Moderate	Very High	Moderate	High

ACCELEROMETER/GYROSCOPE SELECTION

- This gyroscope and accelerometer excels with high accuracy, low power consumption, and integrated features, making it ideal for wearables.

	ICM-42670-P	**ADA BNO055**	**LSM6DS33**
Supply Voltage	1.71V or 3.6V	2.4V to 3.6V	1.71V to 3.6V
Size	2.5mm x 3mm x 0.76mm	3mm x 3mm x .86mm	3mm x 3mm x .86mm
Cost	$2.40	$24.95	$29.95
Free Fall Interrupts	Yes	Yes	Yes
Accuracy	Reasonable	Low	Reasonable
Calibration required	No	Yes	No

LIGHT SENSOR COMPARISON



Photodiodes are highly sensitive, fast, and versatile light sensors that offer a linear response, compact size, and low cost.

Feature/Criteria	Photoresistor	Photodiode	Phototransistor	Photomultipliers
Speed	Slow	Fast	Faster than diodes	Very Fast
Detection Range	Visible Light	Visible, Near Infrared	Visible, Near Infrared	UV, Visible, Near Infrared
Response Speed	Slow	Fast	Moderate	Very High
Amplification	No	No	Yes	No
Sensitivity	Low	Moderate	Moderate	Very High
Voltage Production	No	Yes	No	Yes
Cost	Low	Moderate	Moderate	High

LIGHT SENSOR SELECTION

The VEML7700 is a highly accurate and versatile with I2C interface, wide dynamic range, and low power consumption.

	VEML7700	*AS7262*	*TSL2591*	*GL55xx*
Type	Photodiode	Photodiode	Photodiode	Photoresistor
Supply Voltage	3.3V or 5V	2.7V to 3.6V	3.3V to 5V	N/A
Size	6.5mm x 2.35mm x 3.0mm	90mm x 50mm x 5mm	19mm x 16mm x 1mm	4.3mm x 32mm x 2.1mm
Cost	$7.35	$27.95	$8.48	$0.29
Provide Lux?	Yes	Can be Calculated	Can be Calculated	No

BATTERY SELECTION

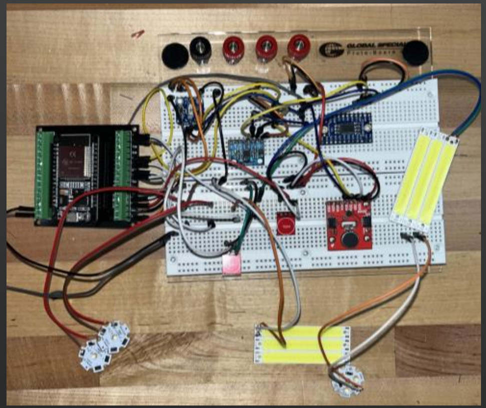
Feature/Criteria	Lithium-Ion (Li-Ion)	Lithium Polymer (LiPo)	Nickel-Metal Hydride (NiMH)
Energy Density	High (150-200 Wh/kg)	High (150-200 Wh/kg)	Moderate (60-120 Wh/kg)
Self-Discharge Rate	0.5-1% per month	5% per month	13.9%-70% per month
Cycle Life	500-1000 cycles	300-500 cycles	300-500 cycles
Voltage per Cell	3.6-3.7V	3.6-3.7V	1.2V
Charge and Discharge current	0.5-1C	1-5C	0.1-1C
Safety	Protection circuit needed	Prone to swelling, overheating	Minimal Risk

DEVELOPMENT HARDWARE

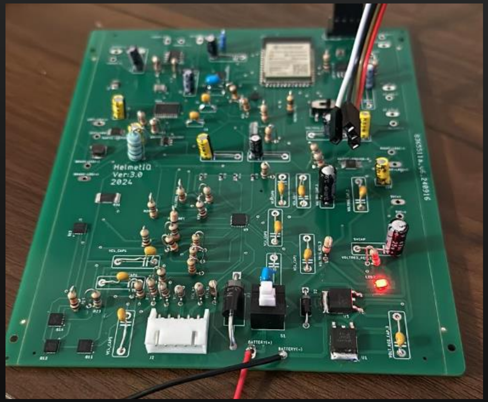
- We choose the ESP32 due to its low cost, amount of GPIO pins, and overall versatility.

Feature	TI CC2652R LaunchPad	Arduino Nano 33 BLE Sense	ESP32
Microcontroller	CC2652R	nRF52840	ESP32 (Xtensa LX6)
GPIO Pins	30	14	36
Wireless Connectivity	Bluetooth 5.1, Zigbee, Thread	Bluetooth 5.0, BLE	WiFi, Bluetooth 4.2, BLE
Power Consumption	Ultra Low Power	Low Power	Low Power
Price	$40-$50	$30-$40	$10-$20
Features	Great for IoT applications	Compact, built-in sensors	Versatile, powerful, low cost
Programming	C/C++, TI-RTOS	Arduino IDE, C/C++	Arduino IDE, C/C++, MicroPython, ESP-IDF

PROTOTYPING AND HARDWARE TESTING



- Prototyping
  - Breakout Boards
  - Breadboard
- Hardware Testing
  - Enable Switch Missing
  - Mixed Ground Plain
  - Trace Cutting
  - Wire Jumping



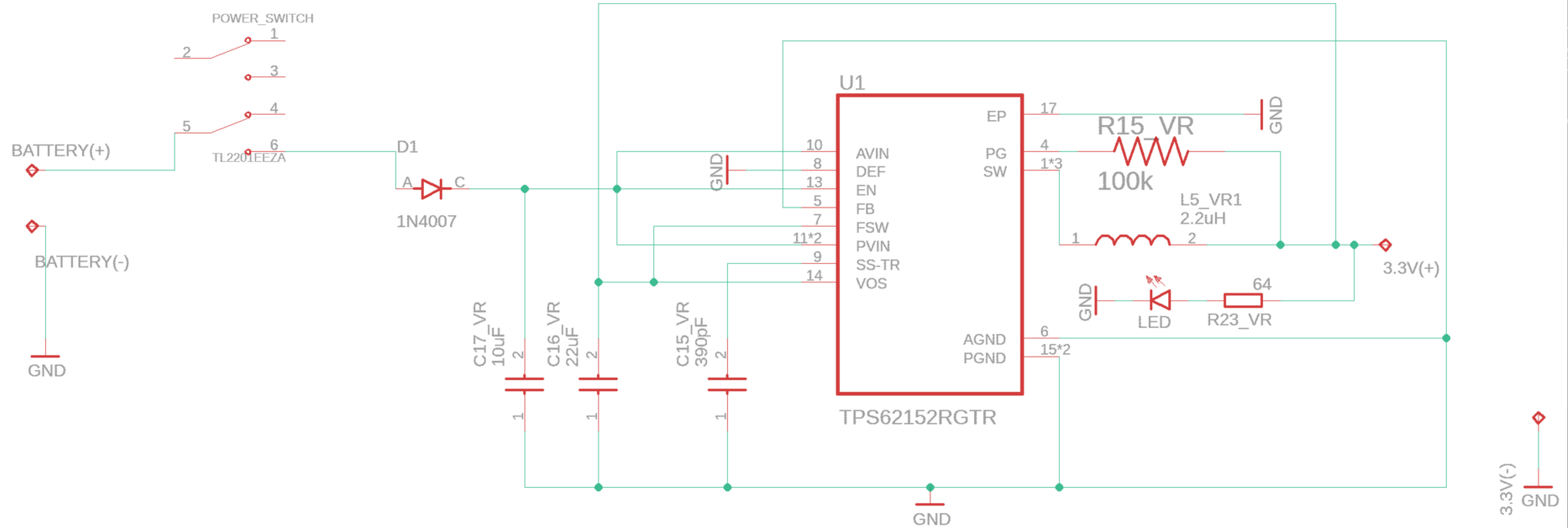
POWER DISTRIBUTION

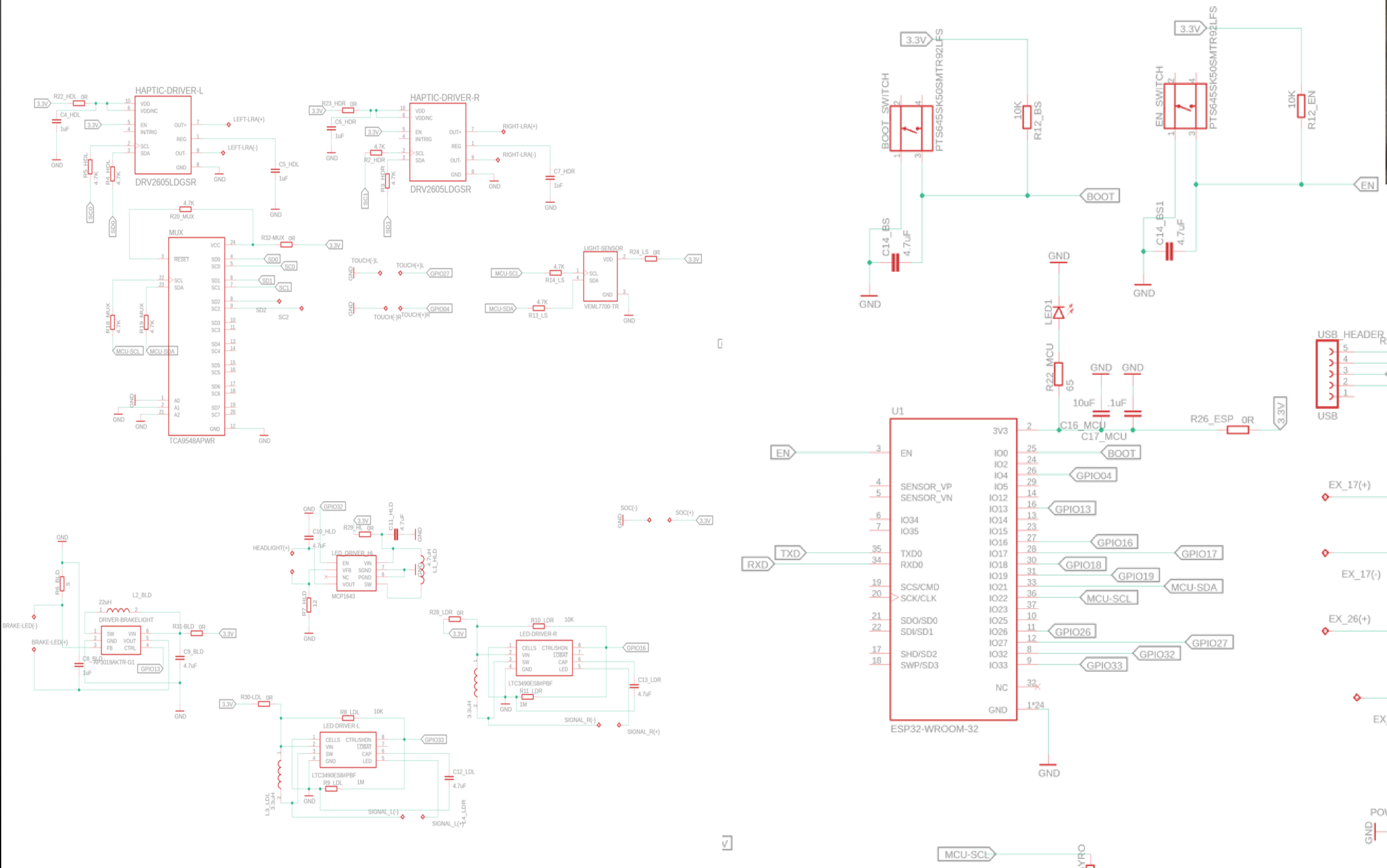
- Total System Power Consumption ~ 2789mW
- Available Power ~ 3300mW

Component	Max Current (mA)	Voltage (V)	Quantity	Total Current (mA)	Power Consumption (mW)
DRV2605L w/ERM Motor	2.3	3.3	2	4.6	15.18
TTP223	0.015	3.3	2	0.03	0.099
ESP32	240	3.3	1	240	792
LTC3490ES8PBF	20	3.3	2	40	132
VEML770	0.045	3.3	1	0.045	0.1485
TCA MUX	0.01	3.3	1	0.01	0.033
AP3019AKTR-G1	560	3.3	1	560	1848
MCP1643	0.05	3.3	1	0.05	0.165
BQ40Z50-R2	0.2	3.3	1	0.2	0.66
VEML7700	0.045	3.3	1	0.045	0.1485
Total					2788.434

POWER SYSTEM CIRCUIT

- Switching Voltage Regulator, Fixed Output 3.3V
- Max Current Output – 1A




HAPTIC-DRIVER-L
DRV2605LDGSR
HAPTIC-DRIVER-R
DRV2605LDGSR
MUX
TCA9548APWR
LIGHT-SENSOR
VEML7700-TR
TOUCH(-)L
TOUCH(+)L
TOUCH(-)R
TOUCH(+)R
MCU-SCL
MCU-SDA
LED_DRIVER_HL
MCP1643
HEADLIGHT(+)
DRIVER-BRAKELIGHT
AP3019AKTR-G1
BRAKE-LED(-)
BRAKE-LED(+)
LED-DRIVER-R
LTC3490ES8#PBF
SIGNAL_R(-)
SIGNAL_R(+)
LED-DRIVER-L
LTC3490ES8#PBF
SIGNAL_L(-)
SIGNAL_L(+)
SOC(-)
SOC(+)
3.3V
BOOT_SWITCH
PTS645SK50SMTR92LFS
10K
R12_BS
BOOT
C14_BS
4.7uF
GND
EN_SWITCH
PTS645SK50SMTR92LFS
10K
R12_EN
EN
C14_BS1
4.7uF
LED1
R22_MCU
65
10uF
.1uF
C16_MCU
C17_MCU
R26_ESP
0R
USB_HEADER
R25_USB
0R
TXD
RXD
USB
U1
EN
SENSOR_VP
SENSOR_VN
IO34
IO35
TXD0
RXD0
SCS/CMD
SCK/CLK
SDO/SD0
SDI/SD1
SHD/SD2
SWP/SD3
3V3
IO0
IO2
IO4
IO5
IO12
IO13
IO14
IO15
IO16
IO17
IO18
IO19
IO21
IO22
IO23
IO25
IO26
IO27
IO32
IO33
NC
GND
ESP32-WROOM-32
GPIO04
GPIO13
GPIO16
GPIO17
GPIO18
GPIO19
GPIO26
GPIO27
GPIO32
GPIO33
EX_17(+)
EX_17(-)
EX_26(+)
EX_26(-)
POWER(-)
POWER(+)


PCB DESIGN

- Power System
  - 3.3V Switching regulator
  - 18650 Sci-gold Batteries
    - 3.6 Volts
    - 12600 mWh
    - High Safety performance
  - Increased trace width
  - Sensor isolation to minimize EMI, improving signal integrity

PCB DESIGN

- MCU
  - ESP-WROOM-32 (has the power and versatility to run everything)
  - 3.3v Input voltage
  - Built-in Antenna
  - Up to 240MHz
  - Strategically placed to minimize trace lengths
  - Maintained antenna isolation, thereby optimizing signal clarity and reducing interference

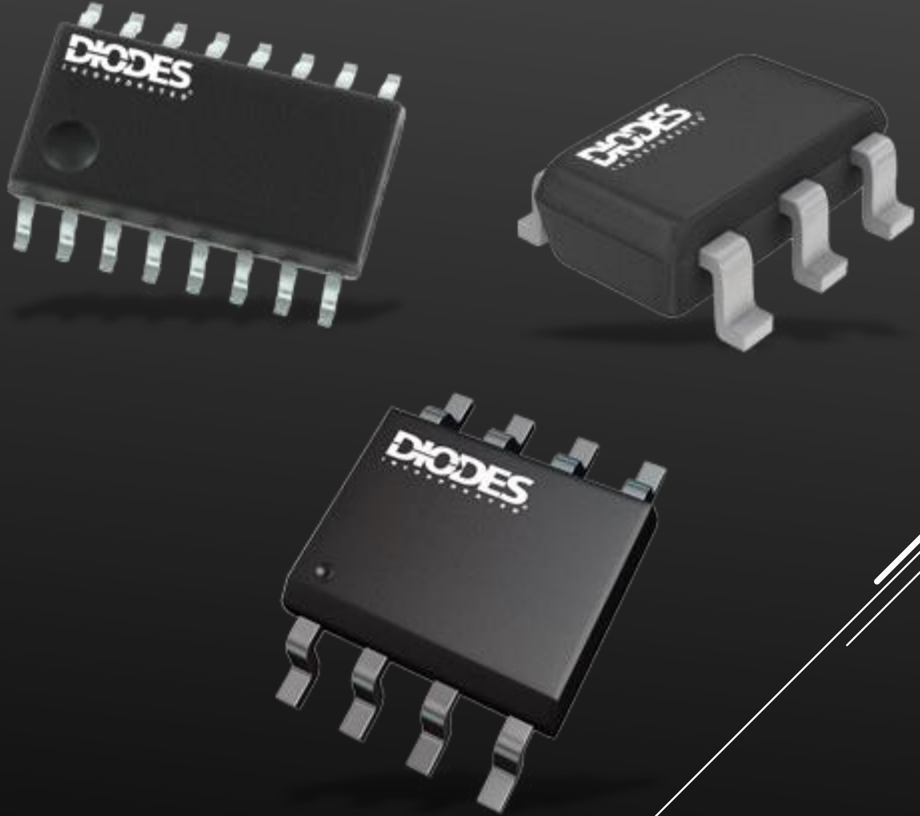
PCB DESIGN

- Sensors
  - Accelerometer and Gyroscope
    - Centralize to keep as close as possible to the center of the bike helmet
  - Light Sensor
    - Maintain a clear field of view for the light sensor to maximize sensitivity and ensure data accuracy.
  - Capacitive Touch Sensor
    - Place close to the edges to minimize interference and wire length.

- Light Sensor (Left) Gyroscope/Accelerometer (Right)

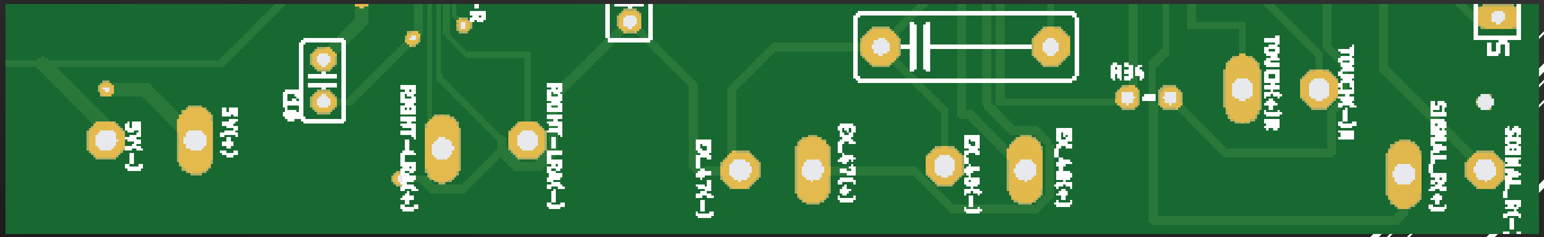
PCB DESIGN

- Drivers
  - Haptic feedback Drivers
    - LRAs
    - Power Supply
  - Dedicated LED’s Drivers
    - Constant Current
    - PWM Dimming
    - Thermal Management



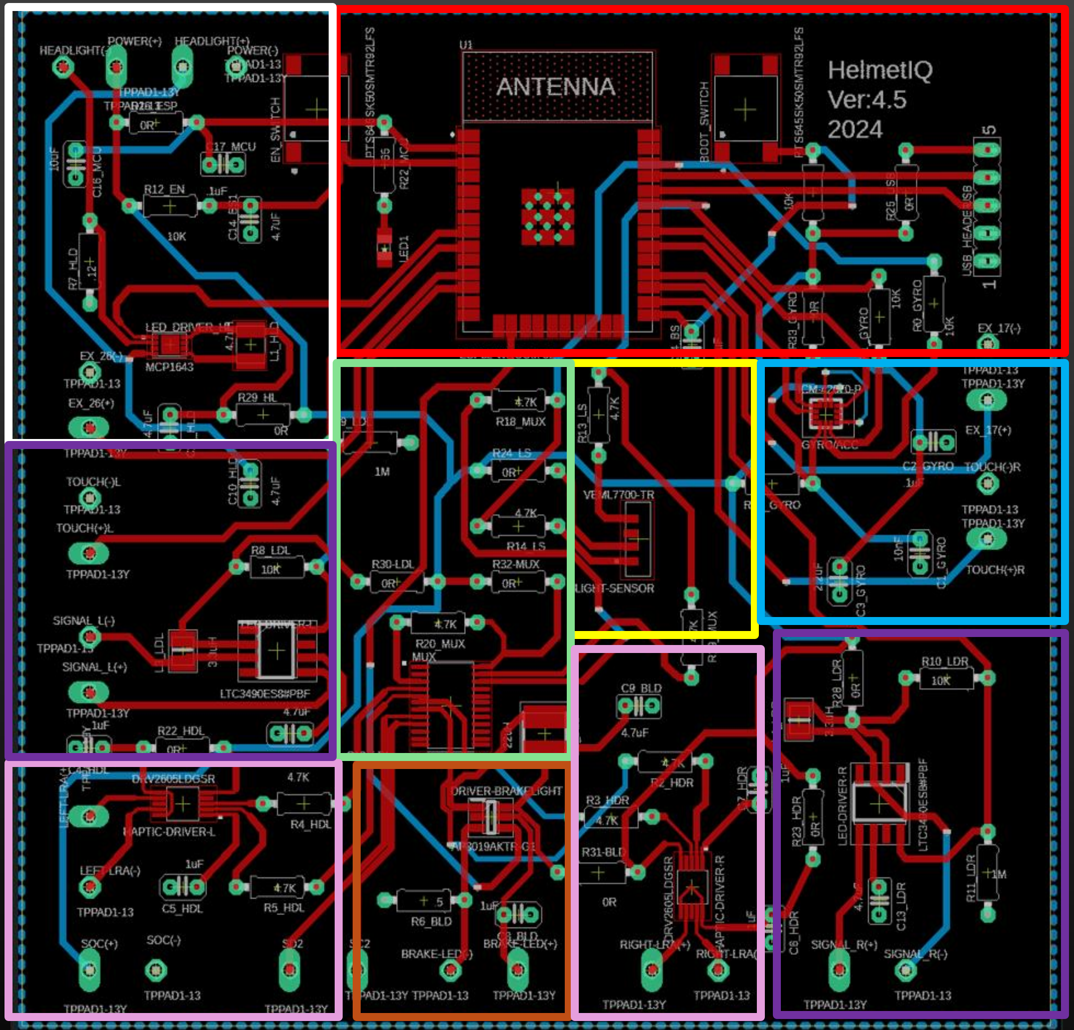
PCB LAYOUT: OPTIMIZING LOCATION

- MCU
- Power System
- Left and Right turn signal Drivers
- Headlight Drivers
- Brake light Drivers
- USB Header
- Pads



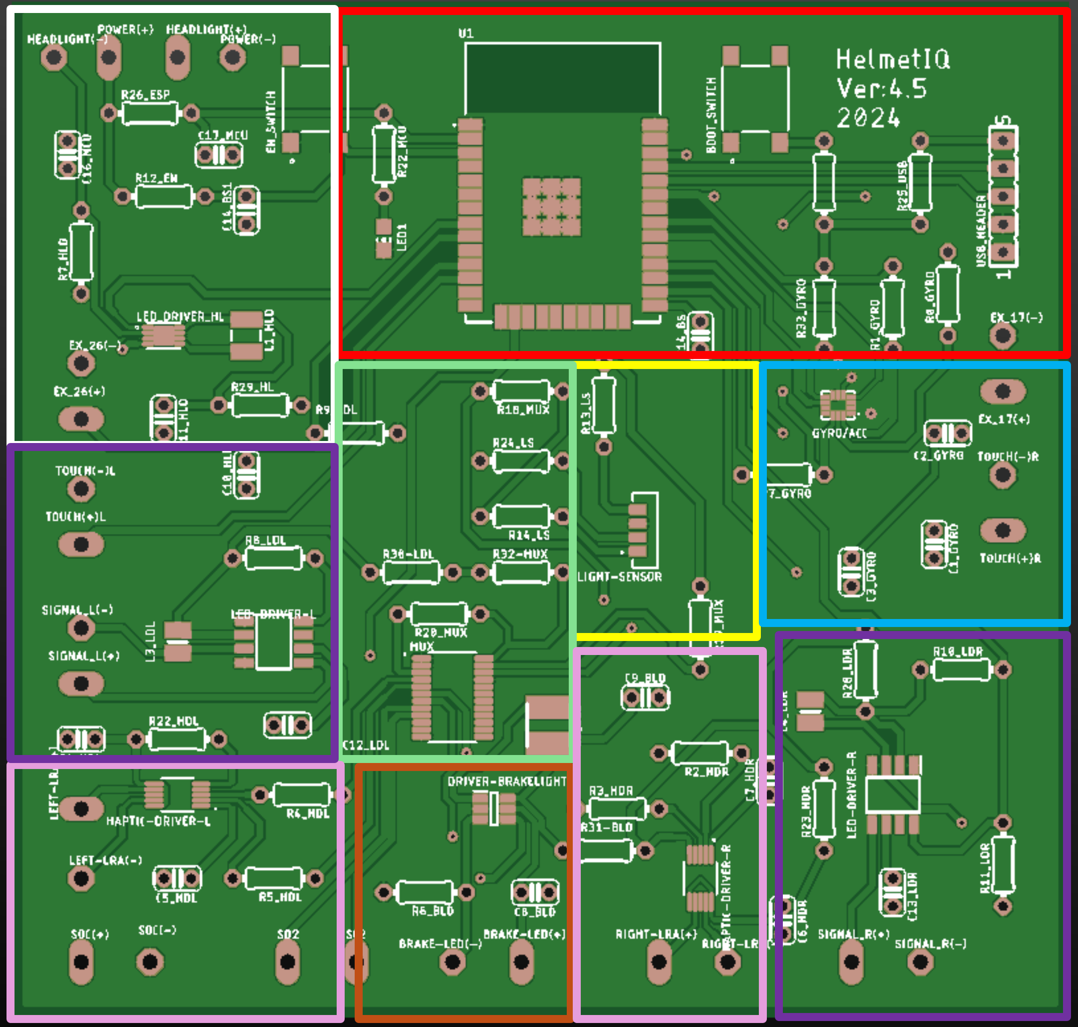
- Optimized locations of different pads

PCB BOARD LAYOUT – MAIN BOARD



- MCU
- MUX
- Left and Right turn signal Drivers
- Headlight Drivers
- Brake light Drivers
- Light Sensor
- Gyroscope/ Accelerometer
- Haptic Driver

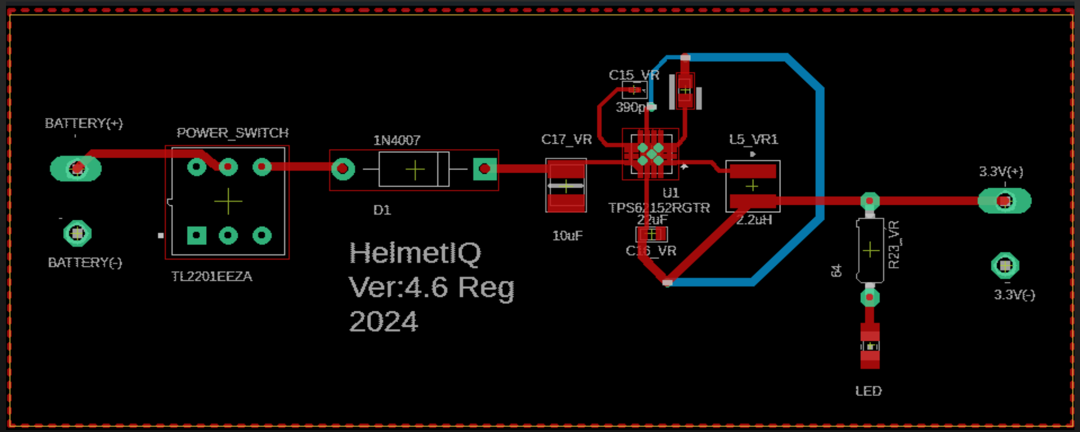
PCB BOARD LAYOUT – MAIN BOARD

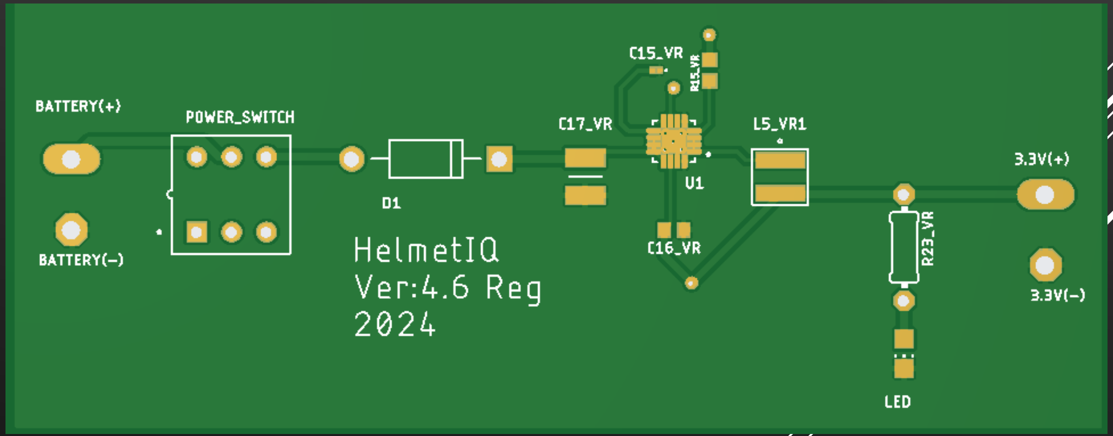


- MCU
- MUX
- Left and Right turn signal Drivers
- Headlight Drivers
- Brake light Drivers
- Light Sensor
- Gyroscope/ Accelerometer
- Haptic Driver

PCB BOARD LAYOUT – REGULATOR

- Fixed 3.3V Switching Regulator





COMMUNICATION PROTOCOLS

- We choose I2C due to its simplicity. I2C can meet all necessary requirements of our project.

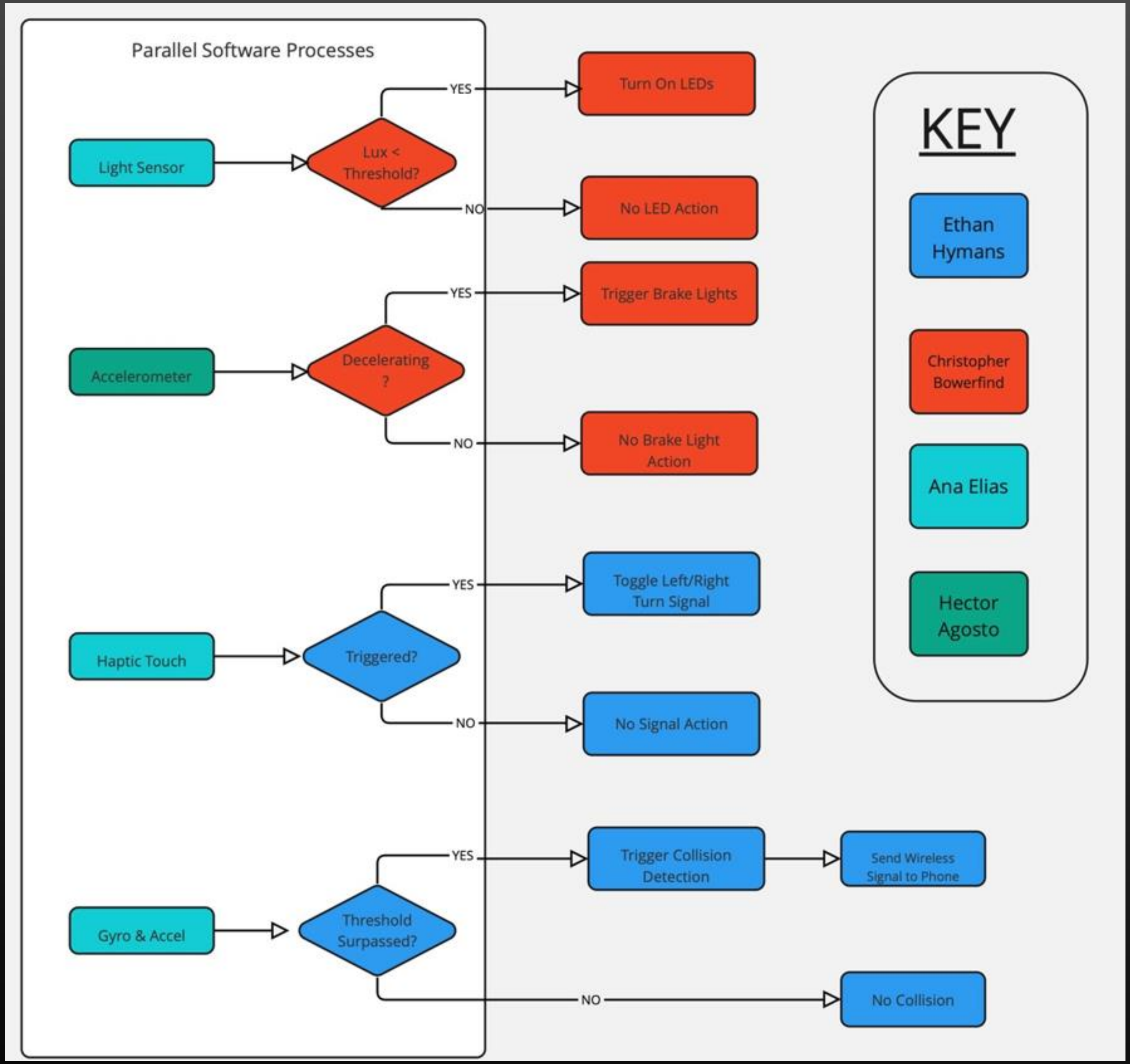
Feature	I2C	SPI	UART
Type	Synchronous	Synchronous	Asynchronous
Wires Required	2 (SDA, SCL) + GND	4 (MOSI, MISO, SCLK, SS) + GND	2 (TX, RX) + GND
Max Speed	3.4 Mbps	10-20 Mbps (typical)	~115 kbps
Hot-Swappable	Yes	No	No
Duplex	Half-duplex	Full-duplex	Full-duplex
Applications	Sensor communication, EEPROM	SD Cards, displays	Debug consoles, GPS modules
Advantages	Simple wiring, multi-device support	Fast, full duplex	Simple, widely supported

WIRELESS COMMUNICATIONS

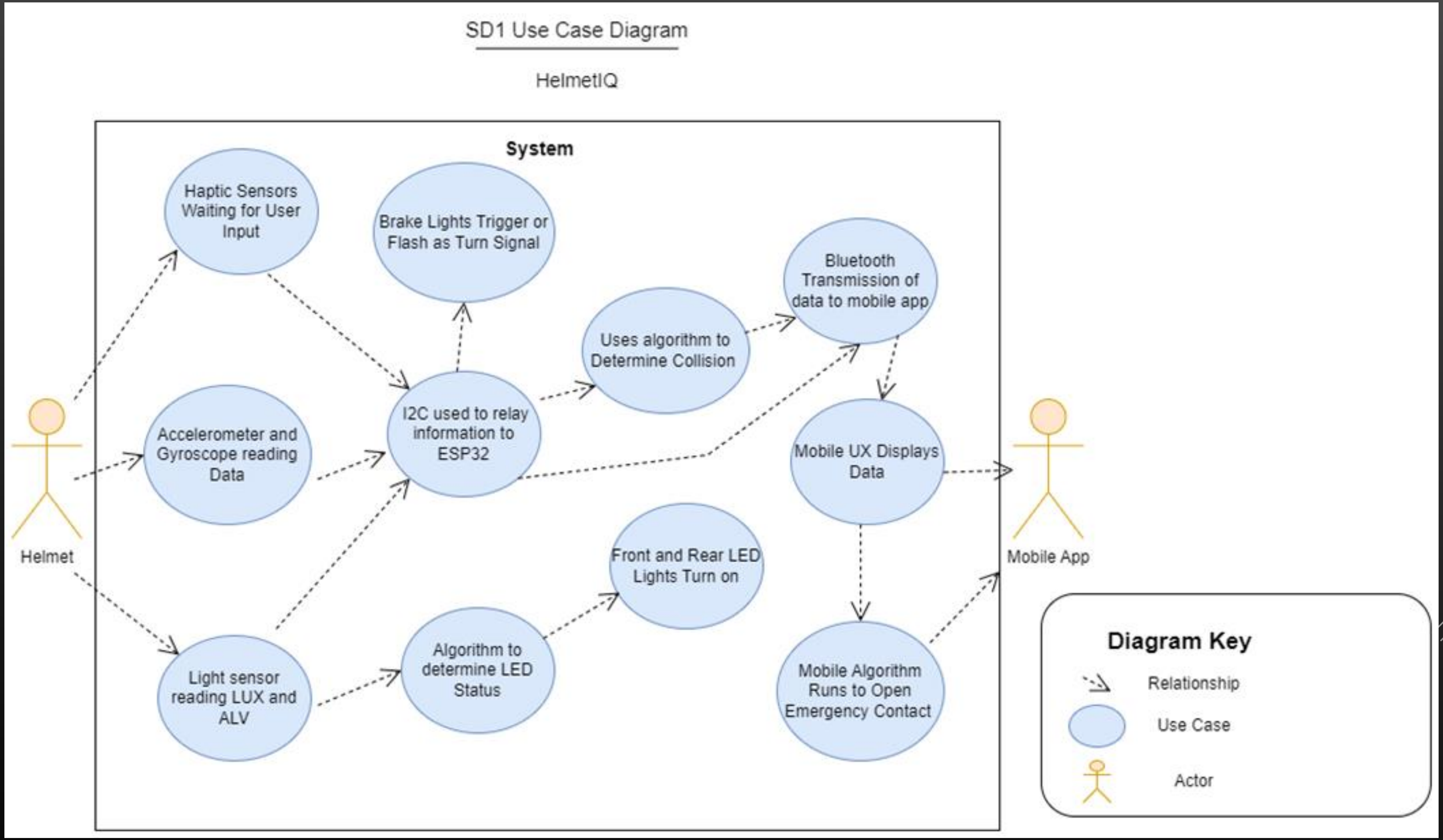
- Bluetooth was chosen for simplicity and ease-of-use. Large data rates are not needed for our project – making Bluetooth the perfect choice.

Comparison Point	WiFi (Soft AP)	Bluetooth
Setup	ESP32 creates its own WiFi network. User needs to connect mobile device to this network. May require app-guided process.	Standard Bluetooth pairing process. Usually simpler and more familiar to users.
Range	Typically, 30-50 meters. Generally longer range than Bluetooth.	Usually 10-30 meters, depending on Bluetooth version and environment.
Data Rate	Up to 150 Mbps for ESP32 in 2.4 G Hz band.	1-2 Mbps for Bluetooth Low Energy (BLE). Adequate for sensor data.
Power Consumption	Higher than Bluetooth LE	Very low power consumption. Ideal for battery-operated devices.
Stability	Stable connection once established.	Generally stable. Uses adaptive frequency hopping to avoid interference.
User Experience	Requires switching WiFi network on phone, which may disconnect internet temporarily.	Seamless connection without affecting phone's main WiFi connection. Might be perceived as easier by users.

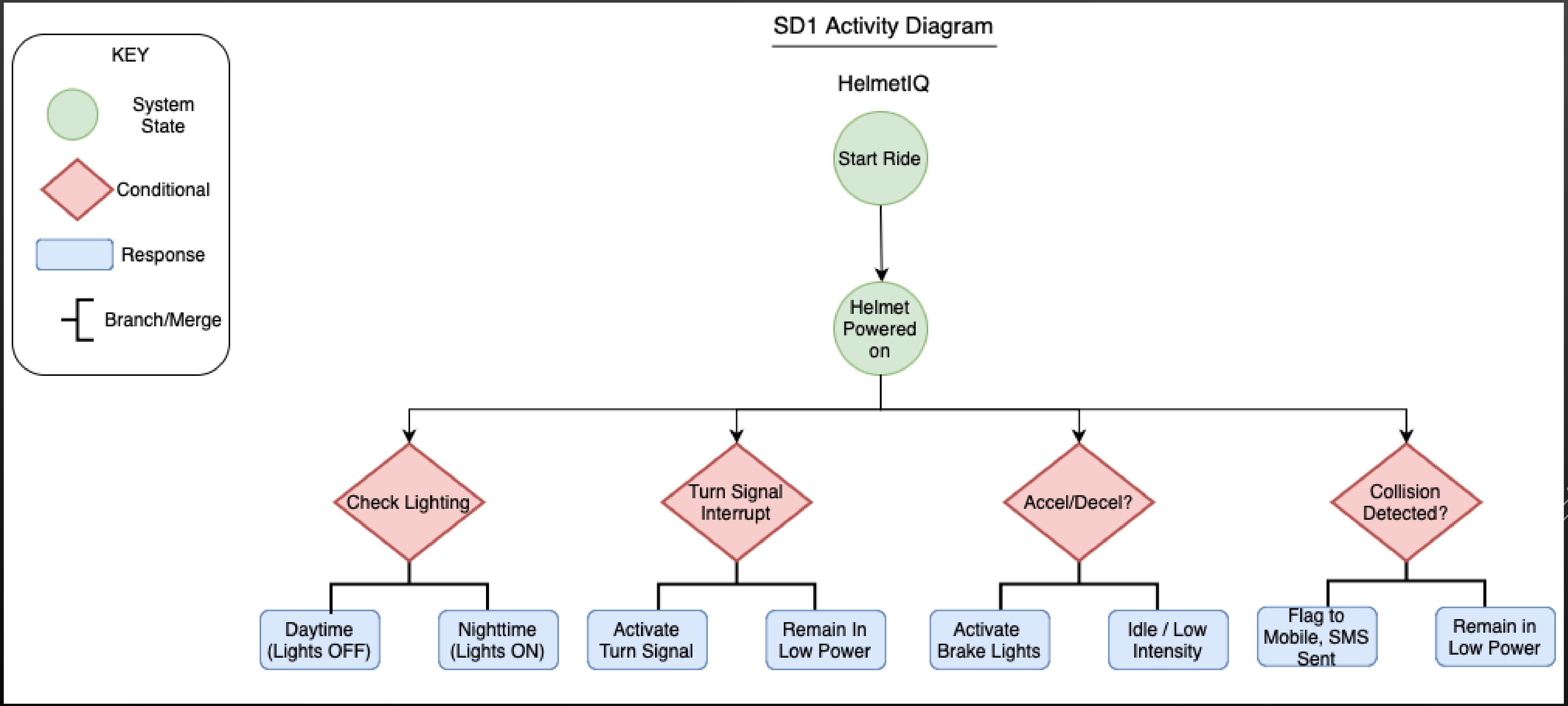
SYSTEM RESPONSE BLOCK DIAGRAM



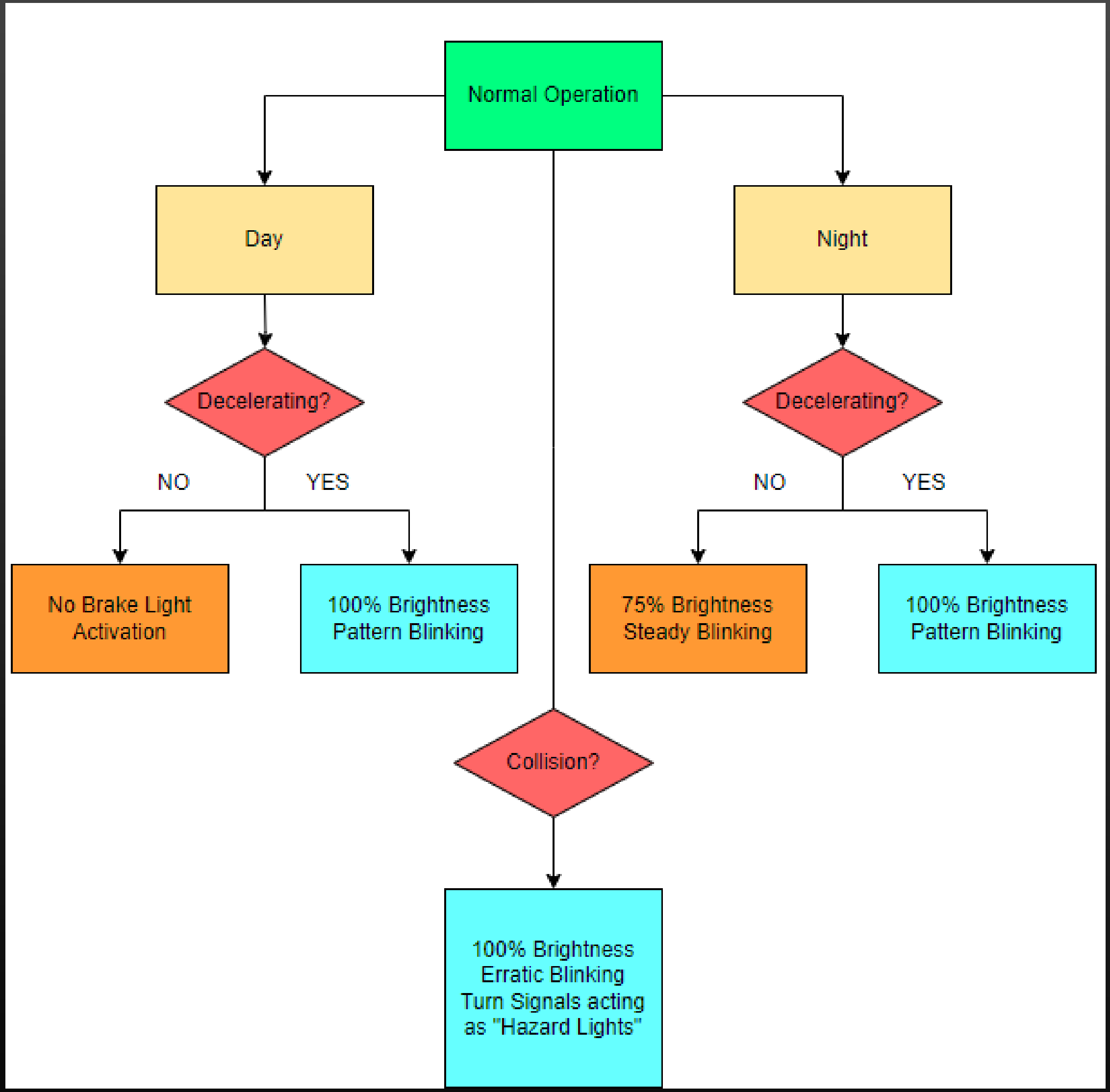
USE CASE DIAGRAM



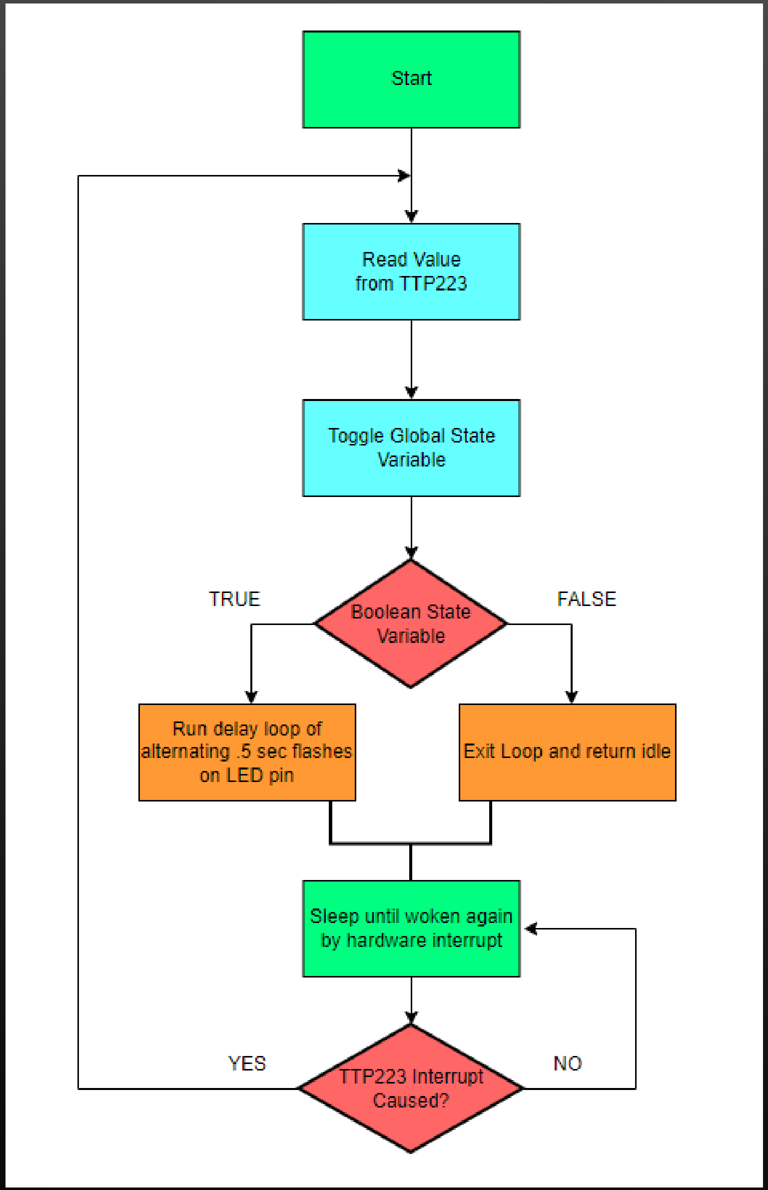
ESP SOFTWARE DESIGN



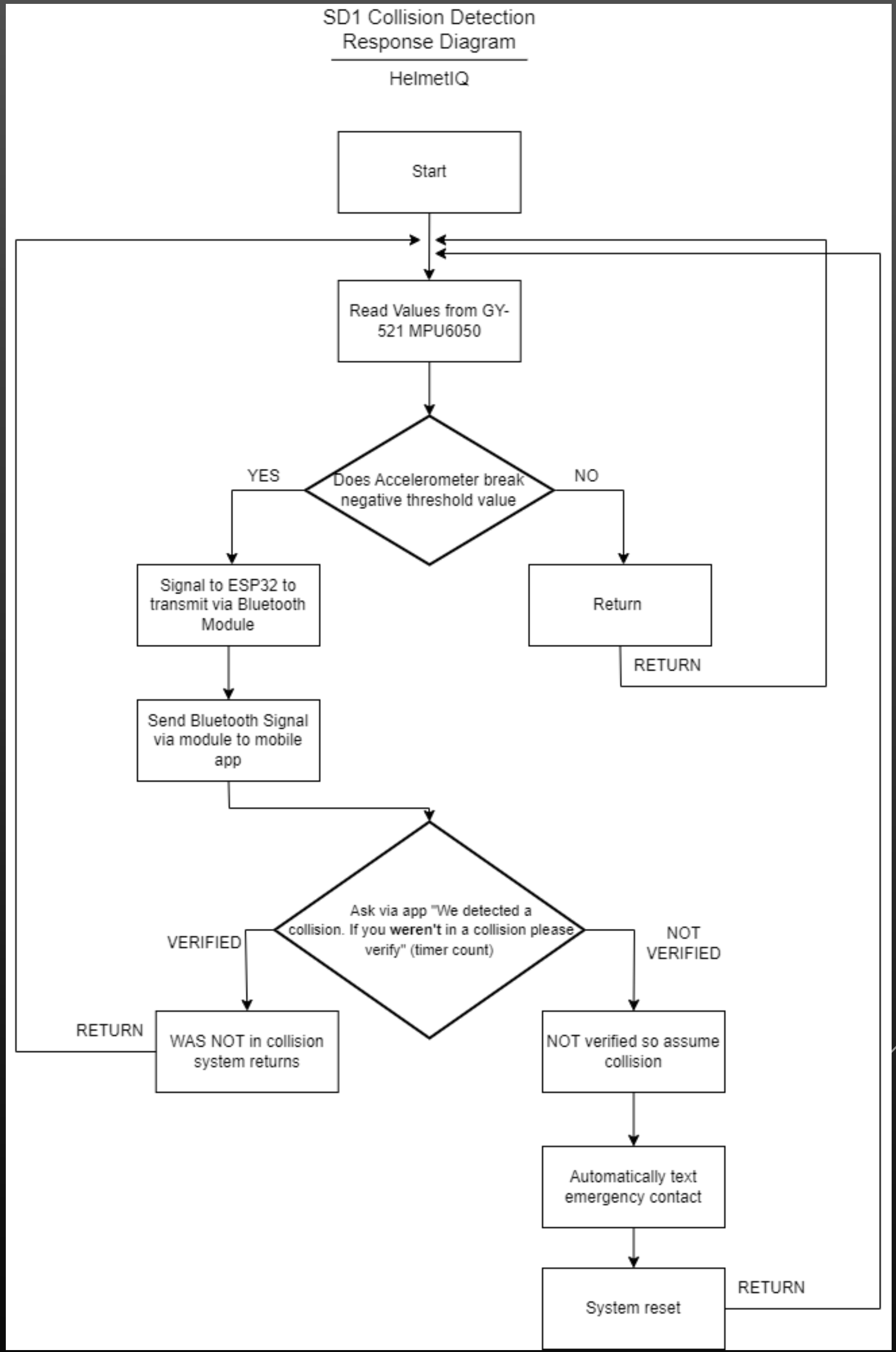
LIGHTING RESPONSE DIAGRAM



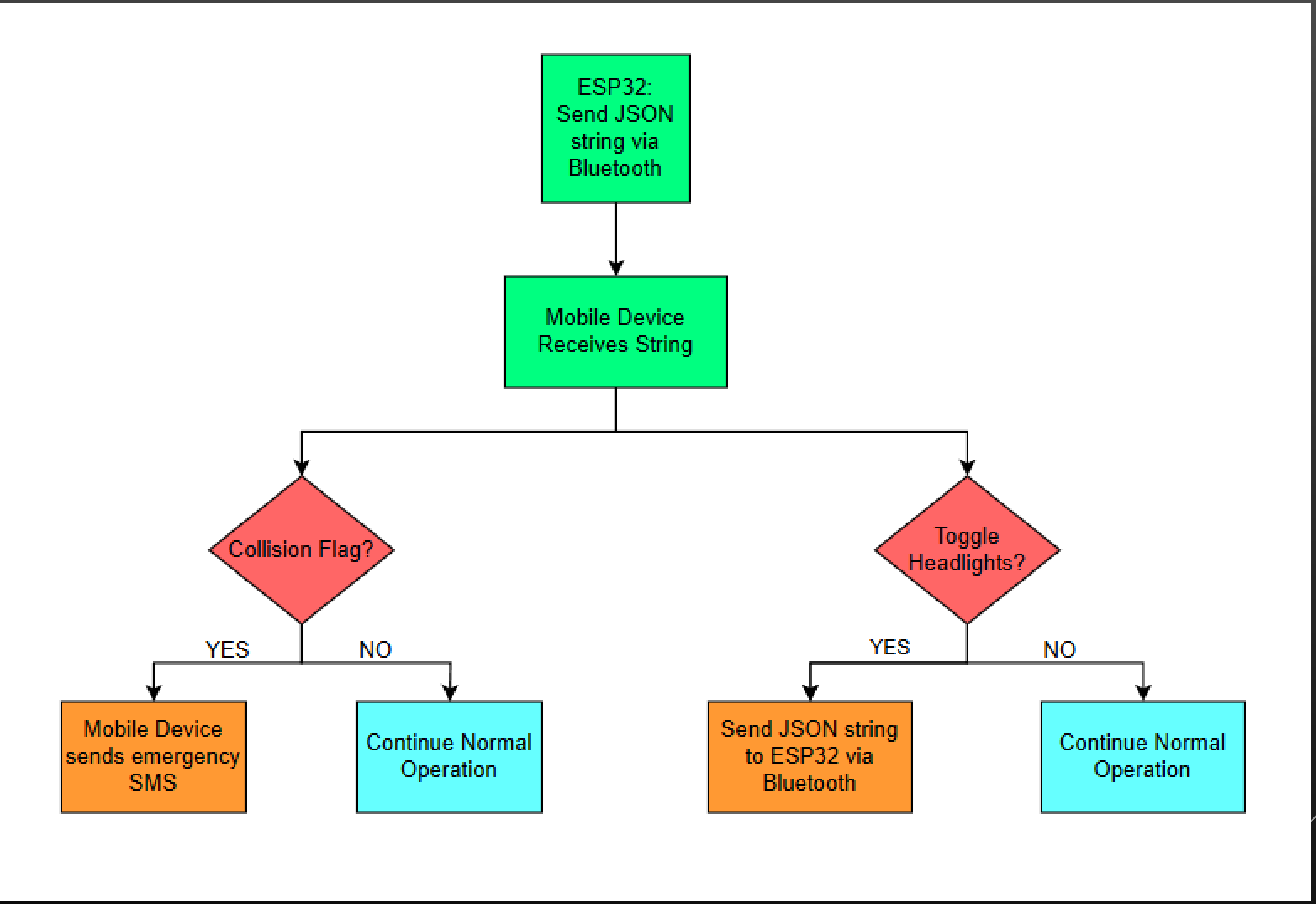
TURN SIGNAL RESPONSE DIAGRAM



COLLISION RESPONSE DIAGRAM



MOBILE SOFTWARE BLOCK DIAGRAM

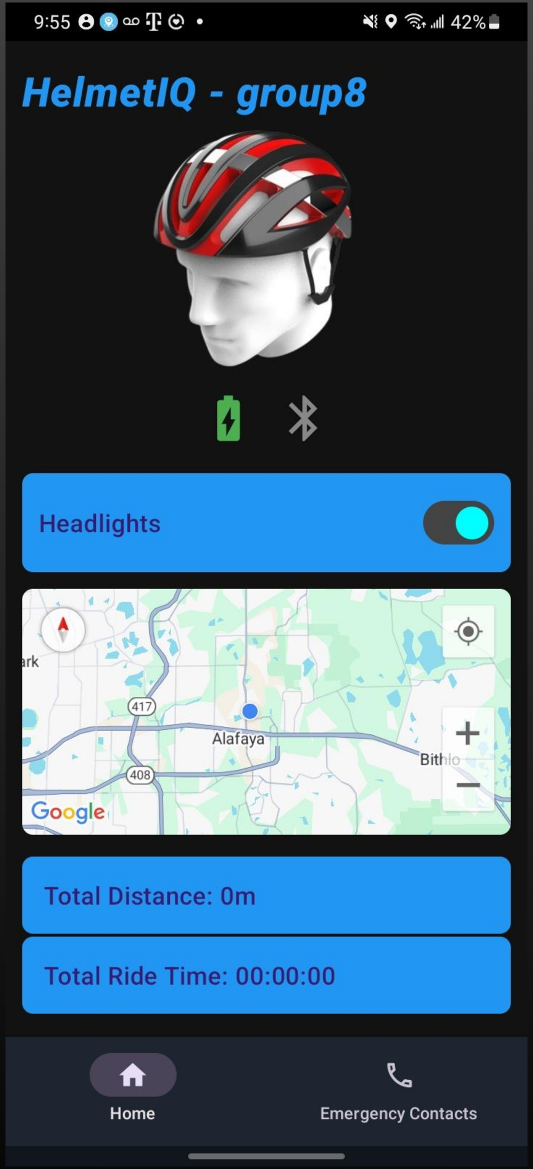


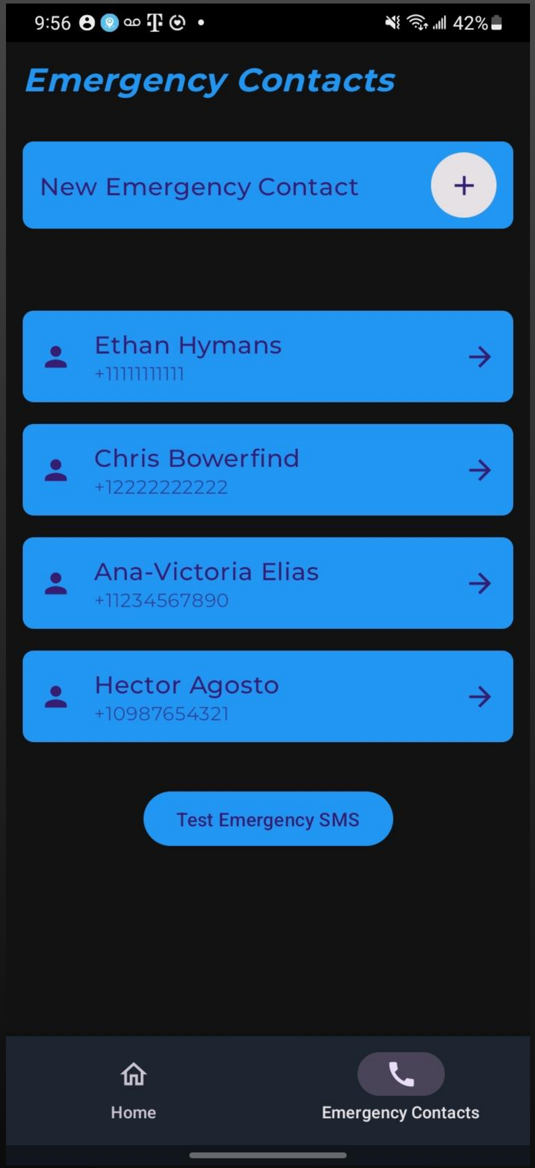
MOBILE DEVELOPMENT

- Android Studio
- Kotlin with Jetpack compose framework

- Samsung Galaxy A32
  - Already on-hand

MOBILE UI DESIGN





PROJECT PROGRESS

- Completed Tasks
  - Adaptive lighting system (automatic night light)
  - First PCB iteration
  - Mobile Android UI
  - Touch sensor turn signals
  - Reading data from accelerometer/gyroscope

PROJECT PROGRESS

- Remaining Tasks
  - Automatic brake light on deceleration
  - Collision detection MCU flag
  - Complete Bluetooth integration between ESP32 and Android App
  - Verify PCB functionality
  - Integrate haptic motors with touch sensors
  - Integrate system into helmet base

WORK DISTRIBUTION

- Ana-Victoria Elias
  - Integration of turn signals, Haptic touch feedback, PCB Design, Battery configuration
- Hector Agosto
  - Integration of headlights, Integration of light sensor, Integration of gyroscope/accelerometer, PCB Design
- Chris Bowerfind
  - Mobile UX, Light Sensor MCU software, LED MCU software, Website Management
- Ethan Hymans
  - Wireless communication, Mobile Development, Helmet Design, SMS Integration, Collision Detection

BUDGET TABLE

Material	Unit Cost	Quantity	Total Cost
Capacitive Touch Sensors	$5.99	2	$11.58
Haptic Drivers	$11.23	1	$11.23
Haptic Motor Driver	$11.23	2	$22.26
ESP32 MCU	$27.00	3	$27.00
LED Strip Lights	$14.99	5	$74.95
Helmet	$30.00	1	$30.00
Battery Rechargable AA	$20.00	2	$40.00
Battery(Li-Ion)	$2.50	3	$7.50
Multiplexer	$6.08	1	$6.08
Accelerometer/Gyroscope	$10.00	1	$10.00
LED Driver	$5.99	3	$17.97
1st PCB	$155.95	1	$155.95
2nd PCB	$88.77	1	$88.77
Digi-key (Parts)	$128.98	1	$128.98
HL-LED/Driver	$16.23	1	$16.23
Gyro-breakout	$9.99	1	$9.99
Light-breakout	$12.99	1	$12.99
Turn-LED	$7.49	1	$7.49
USB-CP2102	$7.49	1	$7.49
BrakeLED	$20.56	1	$20.56
Helmet Base	$15.00	2	$30.00
TOTAL			**$737.02**

QUESTIONS?