SIGHTSENSE

A SMART HAPTIC ALERT OBSTACLE DETECTION SYSTEM FOR THE VISUALLY IMPAIRED

Final Presentation

PRESENTED BY: GROUP 5

Meet the Team

Ana Perez-Jarquin
Electrical Engineer

Jasmine Abraham
Electrical Engineer

Giovanny Garces
Photonic Sciences Engineer

Group 5

Project Background

Need & Impact

- Approximately 2.2 billion people worldwide experience vision impairment or blindness (WHO)
- Assist the visually impaired with greater independence and enhanced safety

Challenge

- Traditional white canes can only detect obstacles by touch
- Limited awareness which can cause accidents in unfamiliar/dangerous environments

Our Motivation

Opportunity

- Improve this essential mobility device through wearable solutions through new technologies

Solution – SightSense: A Smart Haptic Alert Obstacle Detection System for the Visually Impaired

- Obstacle detection
- Haptic (vibration/audio) feedback
- Rechargeable battery
- Work in indoor and outdoor settings

Personal Motivation

- Inspired by a team member's visually impaired relative

GOALS AND OBJECTIVES

The primary goal of the SightSense project is to create a wearable assistive device that will improve mobility and obstacle awareness for the visually impaired.

Basic Goals

- Obstacle Detection
- Operating Time and Consumption
- Response Time
- User Ease of Use

Objectives

- Design a smart device system that detects obstacles within a 2-meter range with a minimum of 90% accuracy.
- Operating continuously for a minimum of 6 hours on a single charge using a rechargeable battery that will guide visually impaired users.
- Implement one 3D light structure sensor and two ultrasonic sensors to enable multi-directional detection, providing real time guidance alerts with <250ms latency to facilitate the users’ use when walking.
- Develop the SightSense system as a strap on attachment that houses all core components, allowing any user to put on within 30 seconds.

Advanced Goals

Objectives

Advanced Goals	Objectives
Detection of multiple forms of obstacles.	Enhance the user experience by incorporating a forward-facing camera module capable of capturing real time environment and detecting at least six object categories (wall, door, person, and tree, table, chair).
Directional haptic alerts to the user in real time.	Implement haptic feedback using a vibrational motor and a speaker, providing directional alerts with a <250ms delay allowing visually impaired users to receive clear guidance alerts in real time.
Audio directional alerts to the user in real time.	Incorporate a voice guidance system that delivers clear, spoken instructions (e.g., Obstacle detected, Turn Left, Turn Right, Stop) around obstacles using audio output, with latency under <250 milliseconds.
Indoor and outdoor functionality.	Optimize system performance for both indoor and outdoor use by calibrating sensors and audio output to adapt to different lighting and ambient noise levels (up to 30dB), ensuring consistent detection for indoor, outdoor, and low light with background noise.

Stretch Goals

App-selectable English/Spanish voice.

Fall detection; Bluetooth/SMS alert

GPS audio navigation to 5 saved spots

SOS double-tap sends location

Objectives

Expand shin guard accessibility by supporting voice feedback in at least two languages (English and Spanish), with a language selection menu available through an app.

Implement fall detection using an accelerometer, with the system triggering emergency alerts via Bluetooth or SMS within 10 seconds of detecting a fall.

Integrate GPS based navigation support using a GPS module, enabling users to navigate to five saved destinations with the user's preference, with audio guidance and <5-meter location accuracy.

Design and implement an SOS alert feature activated by a double tap pressure sensor, to allow visually impaired users to quickly signal for help by sending their location to an emergency contact in <15 seconds.

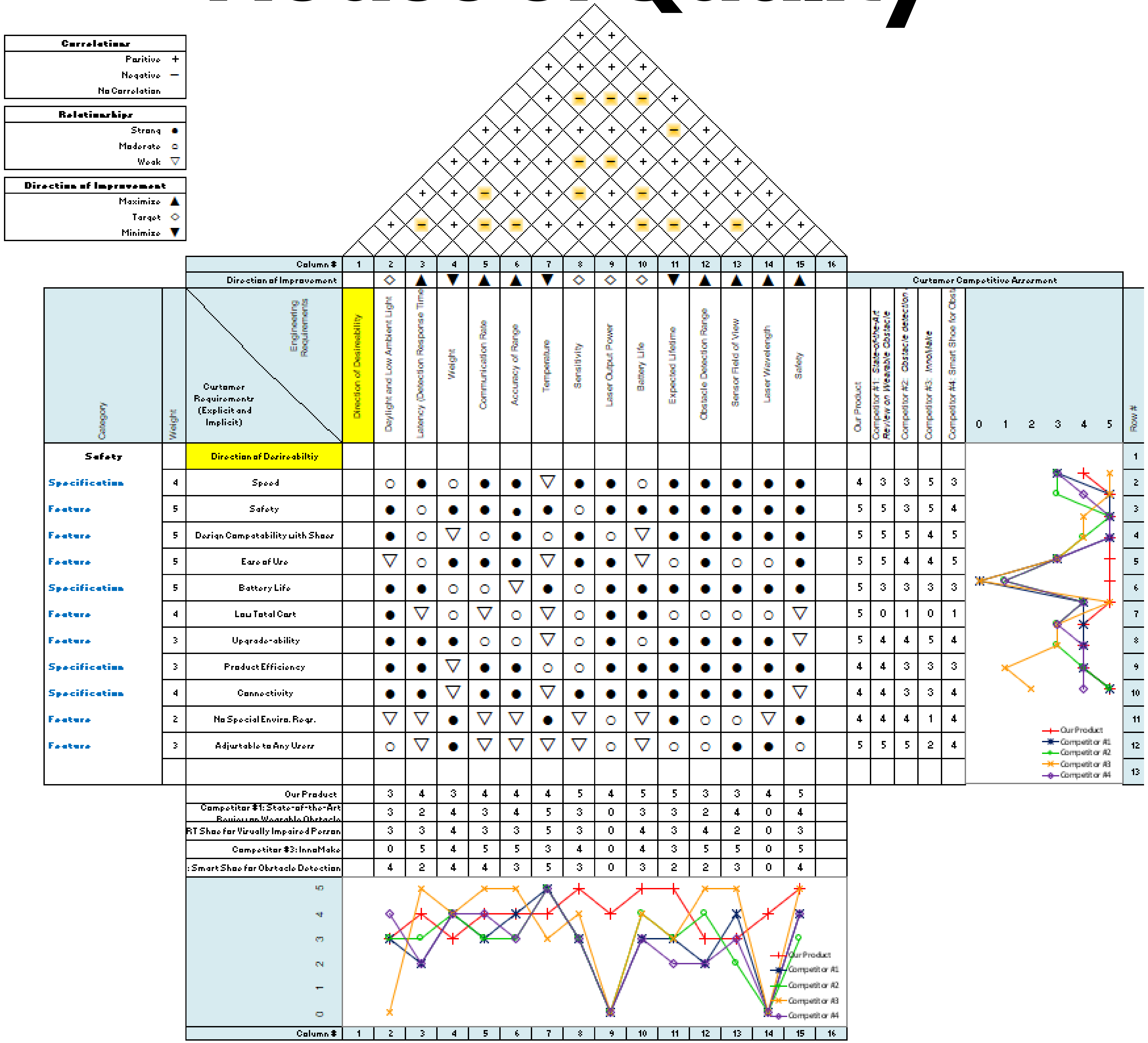
Engineering Requirements

Engineering Requirement	Specification
Accuracy of detection of multiple forms of obstacles (i.e., people, walls, bushes, benches, ditches or drop-offs, steps) must be reliable.	>90%
Range of the distance of obstacle detection in front of the user should be significant.	Up to 2 meters
Detection response time between sensors (i.e., structured light, ultrasonic) and MCU for user notification should be fast.	< 250milliseconds
Battery life for user should last a certain amount of time.	6-10 hours
Device needs to be able to run on a low power battery source.	5 V
Device needs to be wearable and light weight.	< 8 lbs

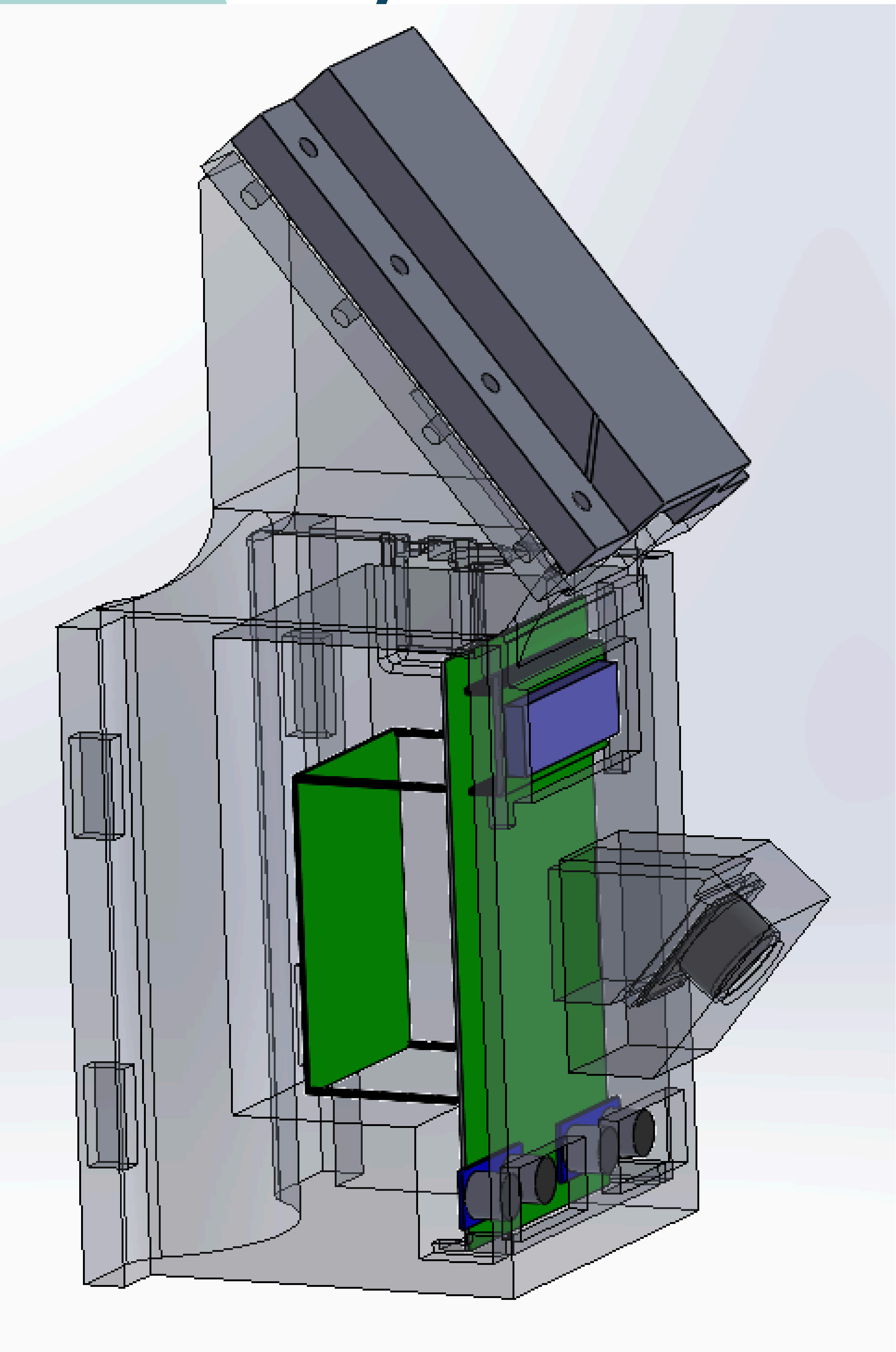
***Highlighted section of table is for the overall system.**

House of Quality

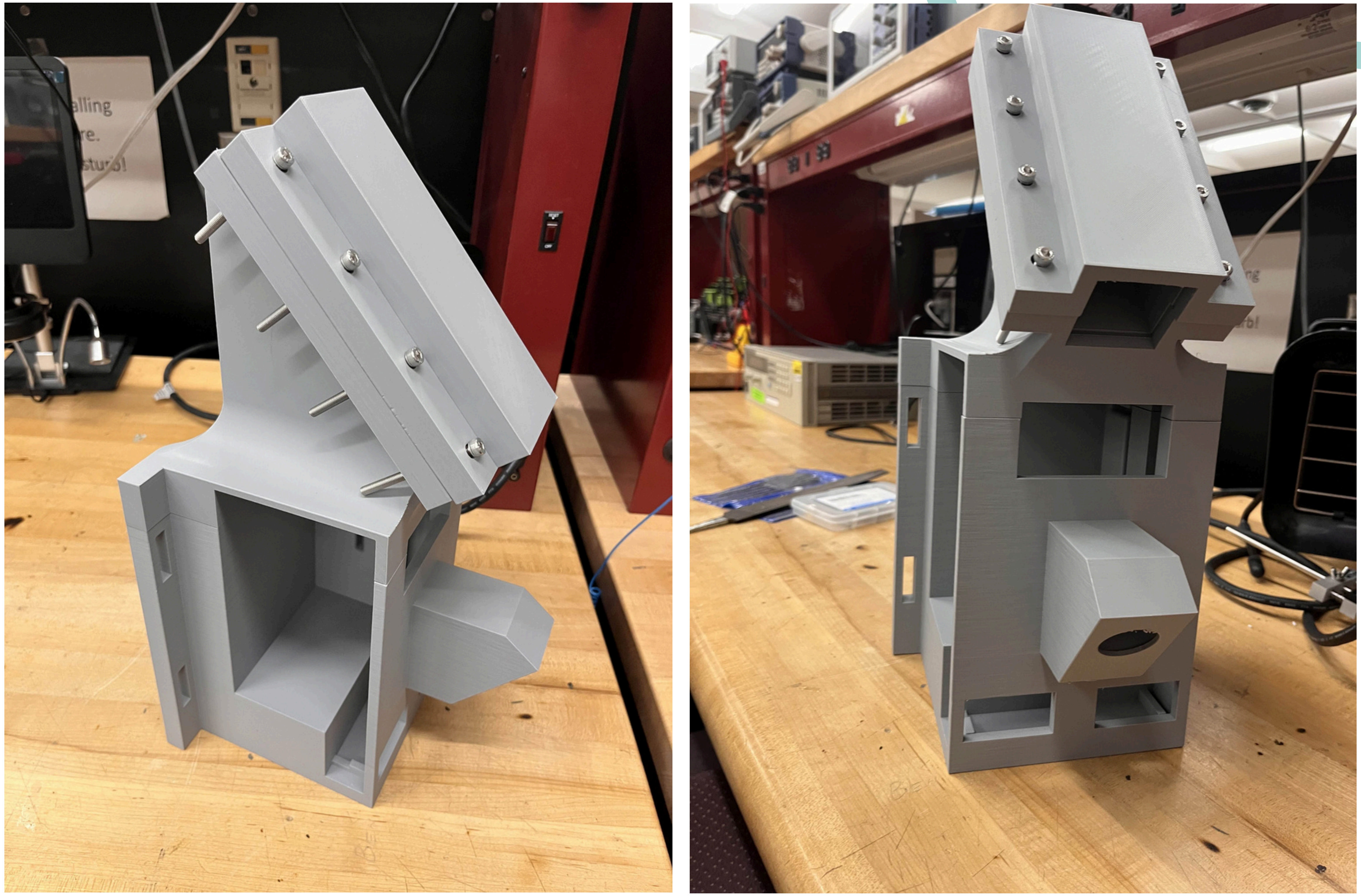
This House of Quality prioritized customer needs (e.g., safety, ease of use, shoe compatibility) to engineering metrics (weight, battery life, detection range, connectivity), shows correlations and trade-offs, and benchmarks competitors to set design targets.



FINAL DESIGN



CAD model



Prototype model

HARDWARE

HW Block Diagram

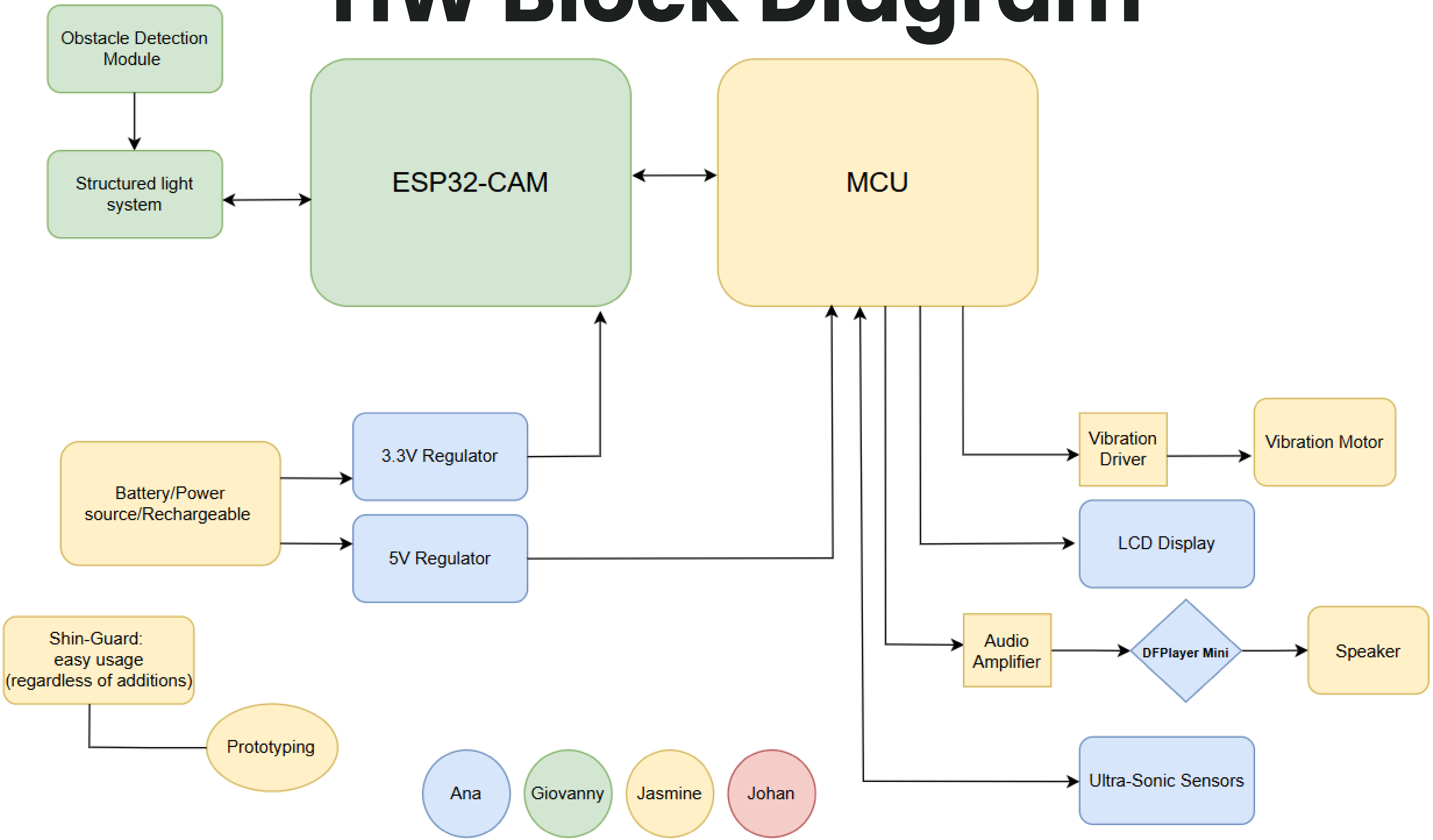


Diagram of how each of the hardware components will interact with one another in the product.

COMPARISON AND SELECTION OF HARDWARE

Main MCU Selection for Overall System

Feature	ESP32-S3-WROOM	STM32F411 (Nucleo / Blackpill)	Raspberry Pi Pico W
Flash / RAM	16 MB Flash, 512 KB RAM (with PSRAM option)	512 KB Flash, 128 KB RAM	2 MB Flash, 264 KB RAM
GPIOs	~34 (varies by module)	~50 (depends on package)	26 GPIOs
Analog Inputs	20 channels, 12-bit ADC	10 channels, 12-bit ADC	3 channels, 12-bit ADC
Communication	SPI, I2C, UART, I2S, CAN, USB OTG	SPI, I2C, UART, CAN, USB OTG	SPI, I2C, UART, PIO (custom protocols)
Strengths	Wireless + AI acceleration + lots of GPIO	Real-time performance + low power	Cheap, simple, PIO for flexible interfacing

Overall, the ESP32-S3-WROOM is the best option for our system as it has a lot of GPIO Pins to use and multiple communication protocols.

MCU Selection for Optical System

Specifications	Raspberry Pi 4 Model B	MSP430FR6989	ESP32-CAM
Processor	Quad-core 1.5 GHz	16MHz	Dual core up to 240MHz
Memory	Up to 8 GB RAM	128KB FRAM	520 KB SRAM + 4MB Flash
Wireless Connectivity	Wi-Fi + Bluetooth	Not Included	Built in Wi-Fi and Bluetooth
Camera Support	Optional	Not supported	Built in camera
GPIO Pins Available	40	83	10
Power Consumption	High	Very Low	Low
Ease of Coding	Low	Moderate	High
Size	Large	Compact	Very Compact
Cost	~$40	~$24	~$15

ESP32-CAM was chosen for its ease of use, built in camera module, and low cost and reliability.

Laser Selection

Part Name	Wavelength (nm)	Output Power	Beam Shape	Driver Included	Price
Lasermate LDM-655-04	650nm	4mw	Elliptical	Yes (TTL Modulated)	$42.00
Hobbyant Red Dot Laser	650nm	200-250mw	Circular	Yes	$30.98
Thorlabs CPS635R	635nm	0.6mw	Circular	Yes	$78.00

Hobbyant laser was selected for higher power output, built in driver, and equal specifications of other lasers will lower price point.

Lens Selection

Lens	Focal Length	Field of View	Mount Type	Lens Type	Distortion	Cost
2.1 mm Wide angle M12	2.1mm	160 degree	M2	Wide angle glass	moderate barrel distortion	$12.00
6 mm M12 Standard	6.0 mm	60 degree	M12	Glass, multi element	moderate	$10
Plano Convex	8.0 mm	na	Lab mount	Single element pcx	minimal	$18

The 2 mm wide angle lens was selected mainly for field of view.

Optical Filter Selection

Part Name	Wavelength	Peak Transmission	Cost
Newport 10XM40-650	630-655 nm	80%	$126.00
Ebay NBP650-40	630-670 nm	94%	$8
Thorlabs FBH650-10	630 -665nm	84%	$192.00

The Newport filter was chosen because of ease of availability, while meeting optical design specifations to match laser.

LCD Screen Display Selection

Feature	OLED 0.96" (SSD1306	LCD1602 (16x2)	TFT 1.44" Color (ST7735)
Display Type	Monochrome Graphics	Text only 2 lines	Full Color Graphics
Interface	I2C	I2C or Parallel	SPI
Resolution	128x64 pixels	16x2 characters	128x128 pixels
Cost	~$8	$3.50	~$8-$12
Power Consumption	Low	Low	High
Ease of Use	Moderate	Low/Easy	High

The LCD1602 I2C is the best option for our system because of the interface works with our main board, low cost, and its low power consumption.

Ultrasonic Sensor

Feature	HC-SR04	JSN-SR04T-3.0	RCWL-1601
Voltage Operation	5V	5V	**3.3V** – 5V
Range	2-400cm	20-400cm	2-440cm
Accuracy	~3mm	~5mm	~5-10mm
Waterproof	No	Yes	No
Size	Compact	Heavy and Large	Small
ESP32-CAM Compatibility	Needs boost converter	Needs boost converter	Yes
Cost	~$3	~$8	~$3
Best Fit for Shoe Project	Yes	No	Maybe

Overall, the HC-SR04 is the best option for our system because of the range that we need is 200cm, its compact size and cost effective.

Vibration Motor Selection

Parameters	Seeed 316040001	DFRobot FIT0774	Vybronics VG0840001D
Size	D: 9.91mm, Thick: 2mm	D: 10mm, Thick: 2.7mm	D: 8mm. Thick: 4.05mm
Weight	0.9g	1.82g	1.27g
Freq.& Sensitivity	Uncontrolled frequency	Uncontrolled frequency	~170Hz (consistent resonant frequency) Optimized for skin contact, commonly used in wearables
Price	$1.20 (in bulk)	$0.99 (each)	$5.39 (each)
Durability	N/A	~100k cycles	Excellent longevity/consistent response
Requirements	None	None	Requires a LRA driver circuit

Selected Vybronics VG0840001D LRA for reliable ~170 Hz resonance, skin-safe wearability, and superior durability - despite higher cost/driver need.

Vibration Driver Selection

Feature	SparkFun 14538	DRV2605L Texas Instruments	Adafruit DRV8833 Dual Motor Driver
Motor Type Standard	ERM vibration motors	ERM and LRA vibration motors	DC motors and vibration motors
Control Interface	Simple PWM control (1 pin)	I2C communication	PWM speed and direction control
Voltage Range	~2V – 5.2V	~2V - 5.2V	2.7V – 10.8V
Current Capability	Works well with small vibration motors	Integrated current feedback control	Up to 1.5A per channel
Built-in Vibration Effects	No	Yes, over 100 pre-programmed effects	No
Ease of Use	High	Low	Moderate
Size	Compact	Small but still needs extra components	Larger
Cost	Cost effective	Higher cost	Cost effective
Best For	Simple vibration	Advanced vibration	Dual motor control

We chose the SparkFun 14538 driver because it’s the smallest, easiest, and most cost-effective option that reliably runs our vibration motor - no extra features we don’t need.

Speaker Selection

Parameters	Same Sky CDS-15158-SMT-TR	Same Sky CDS-20144	PUI Audio AS02708CO-WR-R
Size & Weight	15x15mm (rectangle) 2.1g	20x14.4mm (rectangle) 1.3g	27mm (circular) 4.5g
SPL	87dB @10cm	92dB @ 10cm	88dB @ 10m
Mount Type	Surface	Surface	Through-hole
Frequency	800 Hz - 20 kHz	800 Hz - 20 kHz	300 Hz - 20 kHz
Weather Resistant	No	No	Yes
Power	300mW	1W	0.5W
Impedance	8 Ω	4 Ω	8 Ω

Selected the PUI AS02708CO-WR-R speaker for its weather resistance, wider 300 Hz–20 kHz range, solid loudness, and 8 Ω compatibility - accepting the larger size and lower power.

Audio Amplifier Selection

Feature	Adafruit 2130 PAM8302A Mono Class D Amplifier	PAM8403 Stereo Class D Amplifier	LM386 Analog Audio Amplifier
Type	Class D Mono	Class D Stereo	Analog
Output Channels	1	2	1
Max. Output Power	2.5W at 4-8 Ω	3W at 4 Ω	~0.5W
Voltage Range	2-5.5V	5V	4-12V or 5-18V
Size	Compact	Big	Larger
Efficiency	High	High	Low

We chose the Adafruit PAM8302A mono Class-D amp because it's small, efficient, works on our 3–5 V power, and provides enough volume (~2.5 W) without the size or complexity of the other options.

DFPlayer Selection

Parameter	DFPlayer Mini	DFRobot DFPlayer Mini
Manufacturer	Generic	DFRobot
Audio Output	Mono	Stereo (L/R channels)
Communication Interface	UART	UART
Power Supply Voltage	3.2–5V	3.2–5V
Onboard Amplifier	3W mono	3W stereo
MicroSD Card Support	Up to 32GB	Up to 32GB
File System	FAT16/FAT32	FAT16/FAT32
Library Support	Limited / unstable	Official DFRobot library
Availability	Common, low-cost	Slightly higher cost

We chose the DFRobot DFPlayer Mini because it offers more reliable performance, official Arduino library support, and stereo audio output, making it better suited for consistent and clear audio feedback in our project.

Power Flow Distribution Table

Components	Voltage Requirement	Current Requirement
Battery	Supply None : Delivers 3.7V	1-2A
3.3V Regulator	3.7V	1.2A
5.0V Regulator	3.7V	1.8A
Ultrasonic Sensor: R and L	5V	15mA
LCD	5V	15-30mA
Laser	3.3V	25mA max current draw
ESP32-CAM	5V	~500mA
ESP32-S3-Wroom	3.3V	~500mA
Vibration Driver	3.3V	70-90mA
Vibration Motor	3.3V	90mA
Audio Amplifier	5V	Low current draw: 4mA quiescent and 1uA in shutdown mode
Speaker	5V	0.25A

Battery Selection

Features	Meshnology 3000 mAh 3.7 V Li-Ion	Adafruit 150 mAh	SparkFun 2.6 Ah
Battery Type	103665 Li-Ion Cylindrical Cell (protected)	Li-Po Pouch Cell	18650 Li-Ion
Voltage	3.7V	3.7V	3.7V
Current	~2–3 A (continuous, protection limited)	~200 mA	~2–3 A
Protection Circuit	Yes (built-in)	No	No
Connector	Bare leads (insulated, can be soldered)	JST-PH 2-pin	Bare terminals
Price	~$14.00 (Amazon)	~$5.95	~$11.00

We chose the Meshnology 3000 mAh Li-ion for its high capacity, 2–3 A output, built-in protection, and good cost - better fit than the tiny 150 mAh pouch or the unprotected 18650.

3.3V Regulator

Components	TPS613221	Pololu 2122 (D24V3F3)	Pololu 2855 (D24V5F3)
Input/Output Voltage	0.9-5.5V/Fixed 3.3V	4.5-42V/Fixed 3.3V	4.5-36V/Fixed 3.3V
Max Output Current	~600mA cont., 1.2A peak	300mA cont.	500mA cont.
Features	Simple, tailored	Wide VIN range, compact	More current headroom, compact
Size	Custom PCB (any size)	0.35" x 0.45" (9mm x 11mm)	0.4" x 0.5" (10mm x 13mm)
Best Use	Direct from battery (3-4.2V)	Stepping down from higher rails	Stepping down from moderate rails

We chose the TPS613221 for 3.3 V because it’s a small, custom PCB solution that runs directly from our 3–4.2 V battery and delivers enough current, unlike the larger Pololu modules.

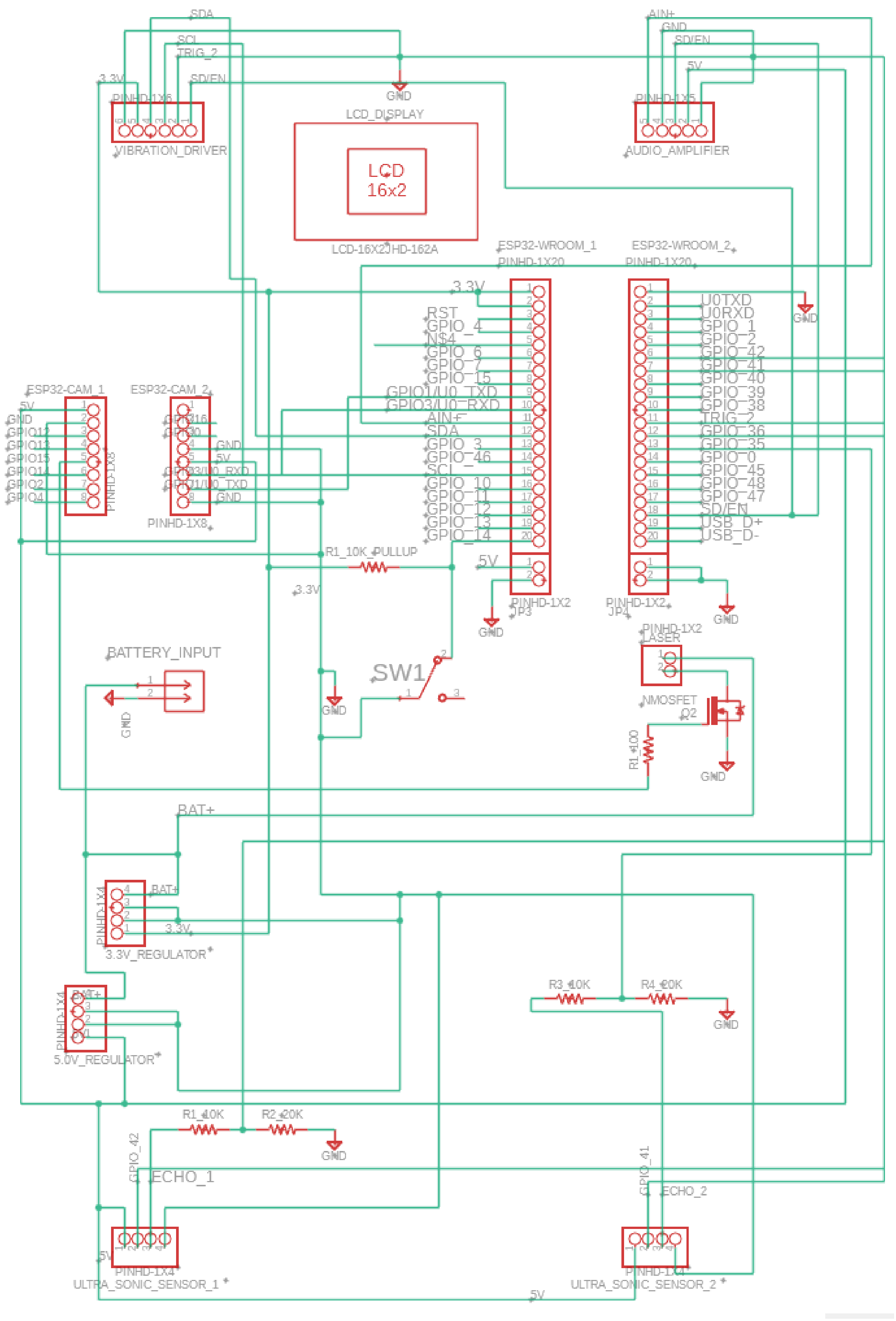
5.0V Regulator

Components	**TPS613222**	**HiLetgo DC-DC Step Up Booster Converter**	**AliExpress Mini Boost**
Input Voltage	0.9-5.5V	2-24V	2-24V
Output Voltage	Fixed 5V	Adjustable up to ~28V	Adjustable up to ~28V
Max Output Current	1.2A peak, ~500-600mA continuous	~1-2A (depends on cooling)	~1A
Key Features	Designed to spec, stable, fixed 5V, LED indicator	Cheap , adjustable pot, no protection	Tiny, adjustable pot, minimal components
Size	Custom PCB	~37mm x 17mm	Very small (~22mm x 14mm)

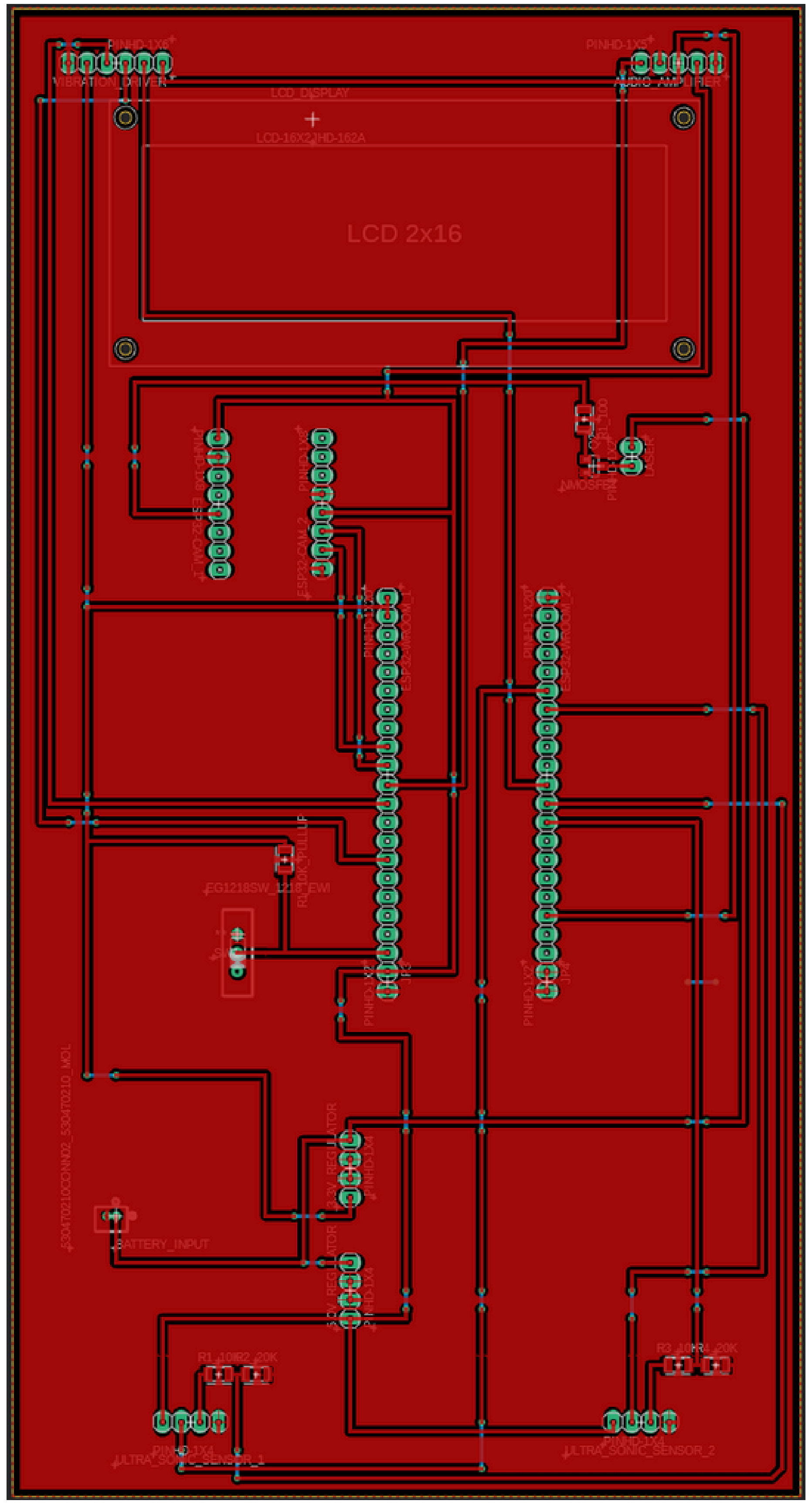
We chose the TPS613222 for 5V because it gives a stable, fixed 5V with enough current on a small custom board - unlike the cheap adjustable modules that lack protection.

SCHEMATICS AND PCB'S

Main Board

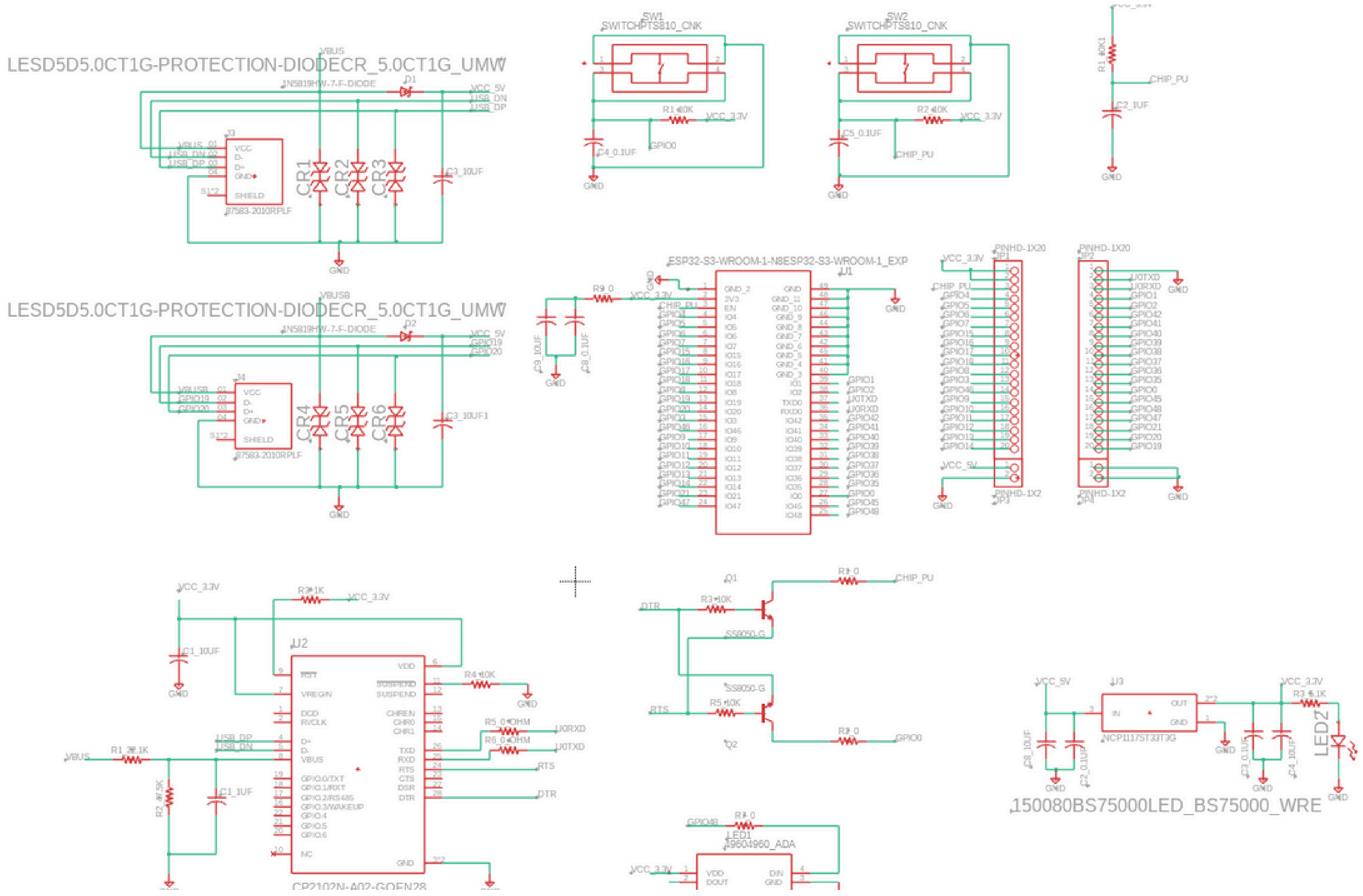


Schematic

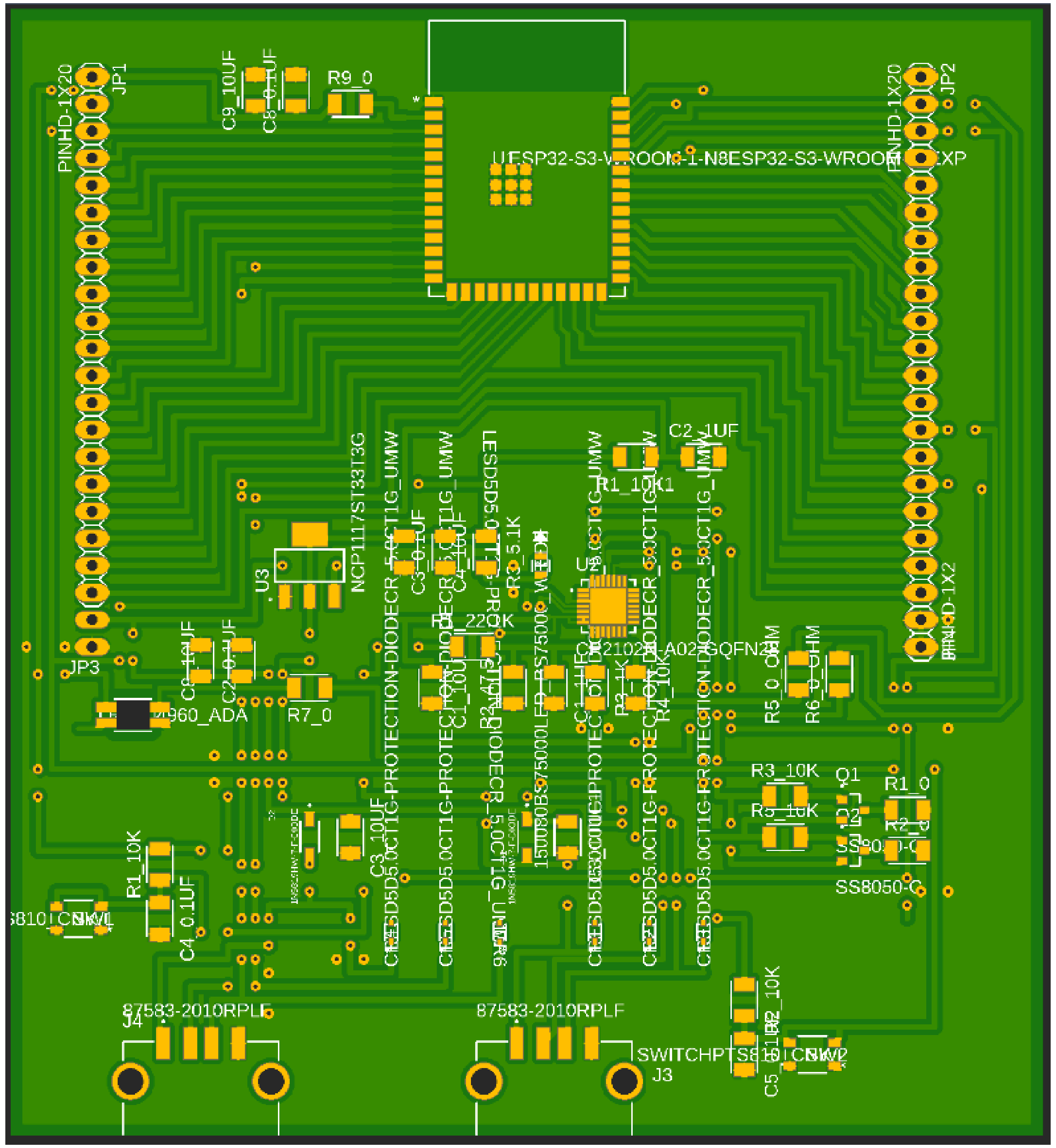


PCB

MCU: ESP32-S3-WROOM

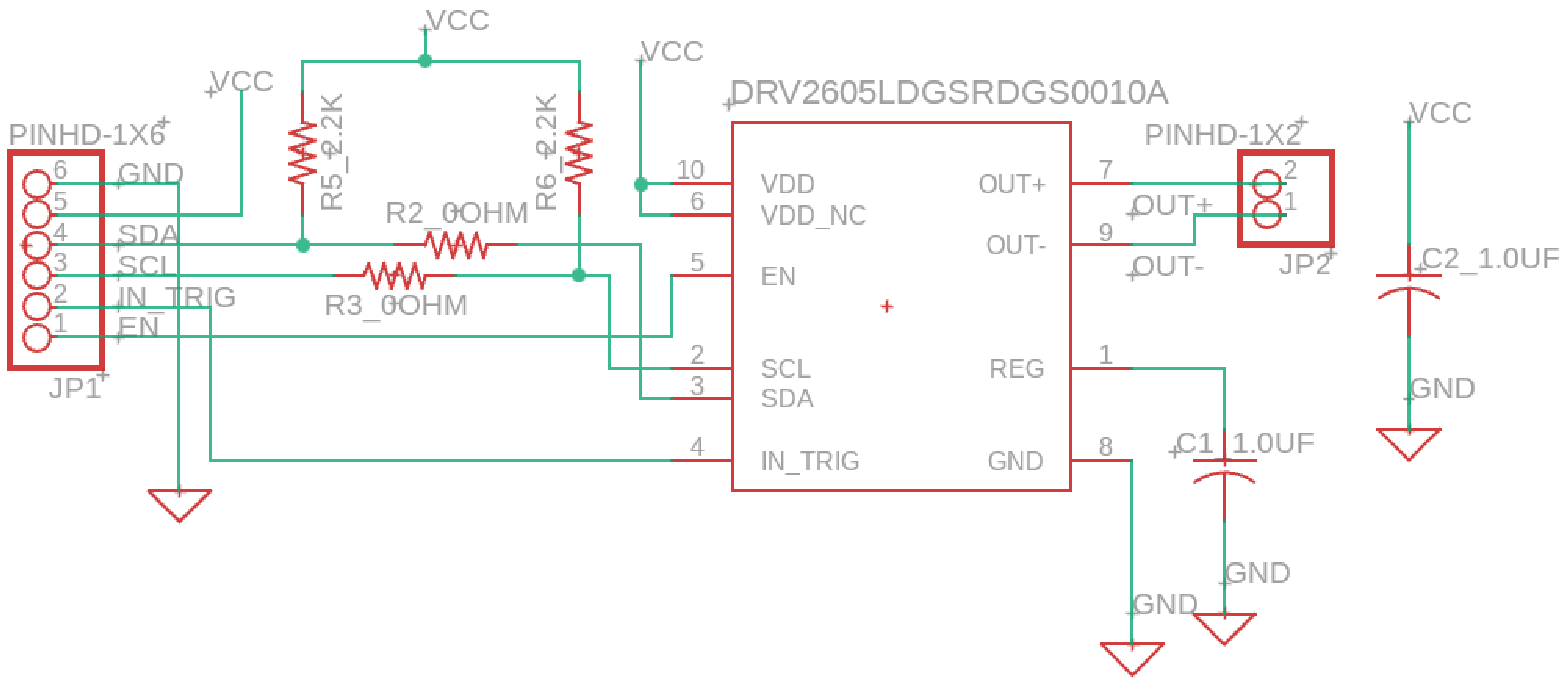


Schematic

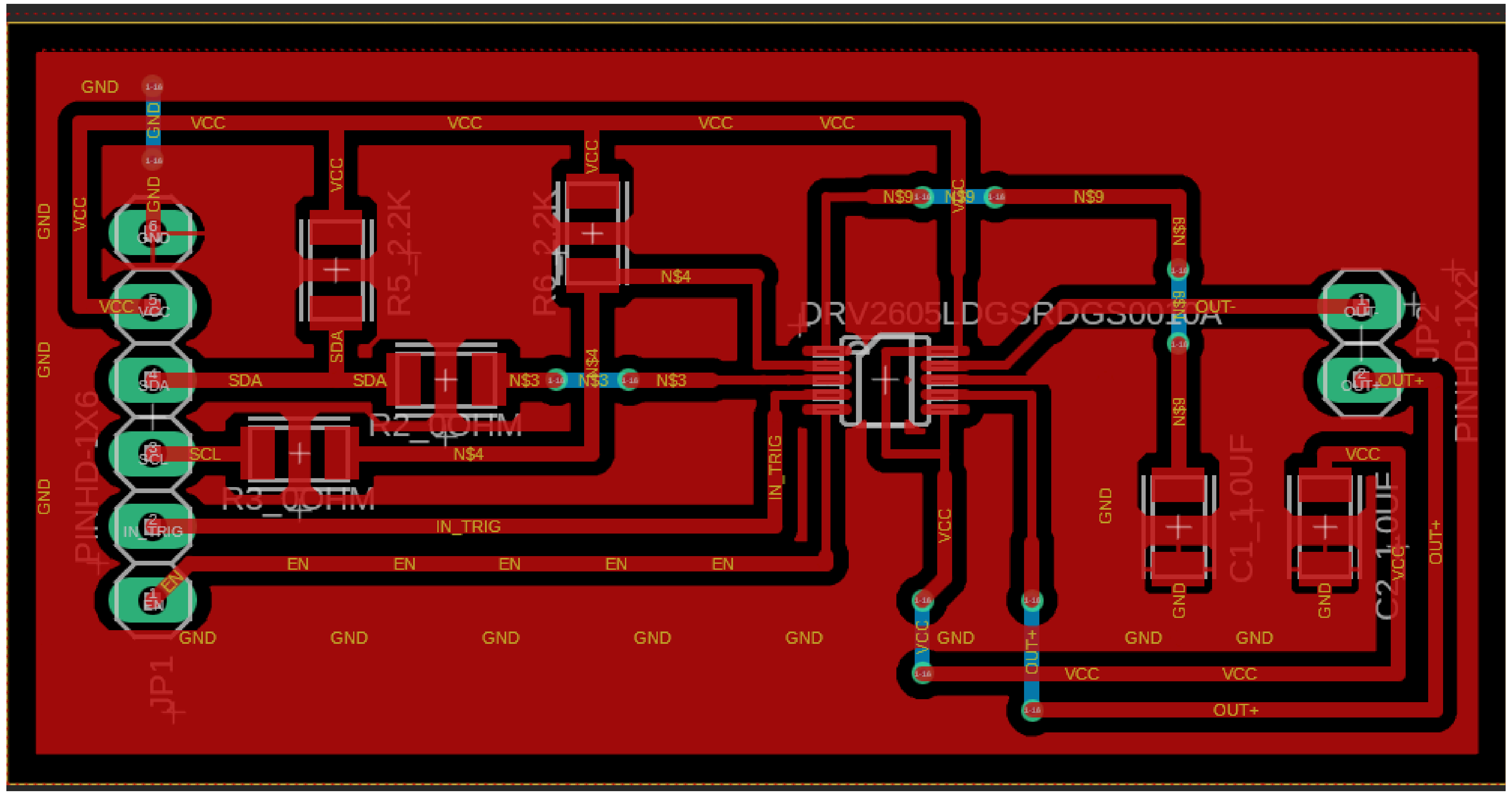


PCB

Vibration Driver

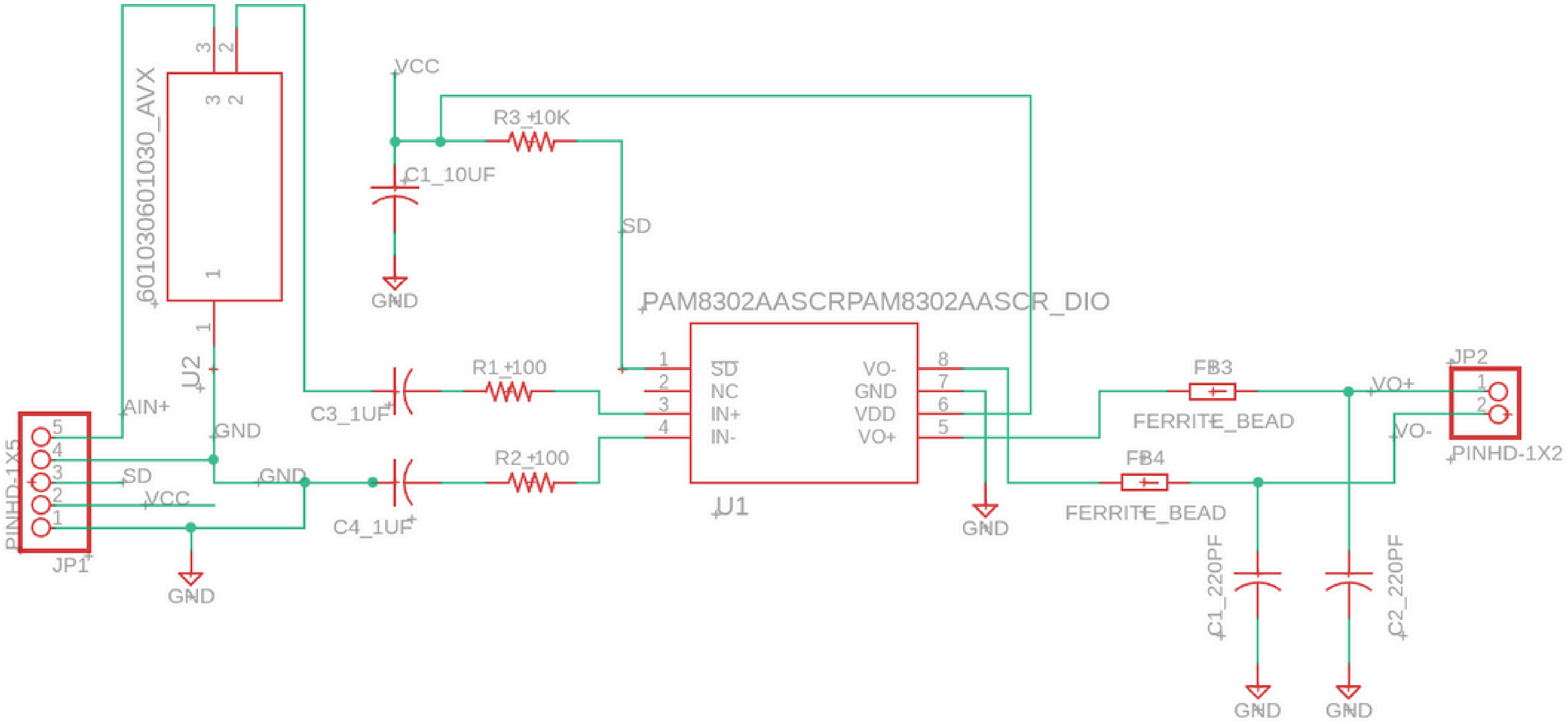


Schematic

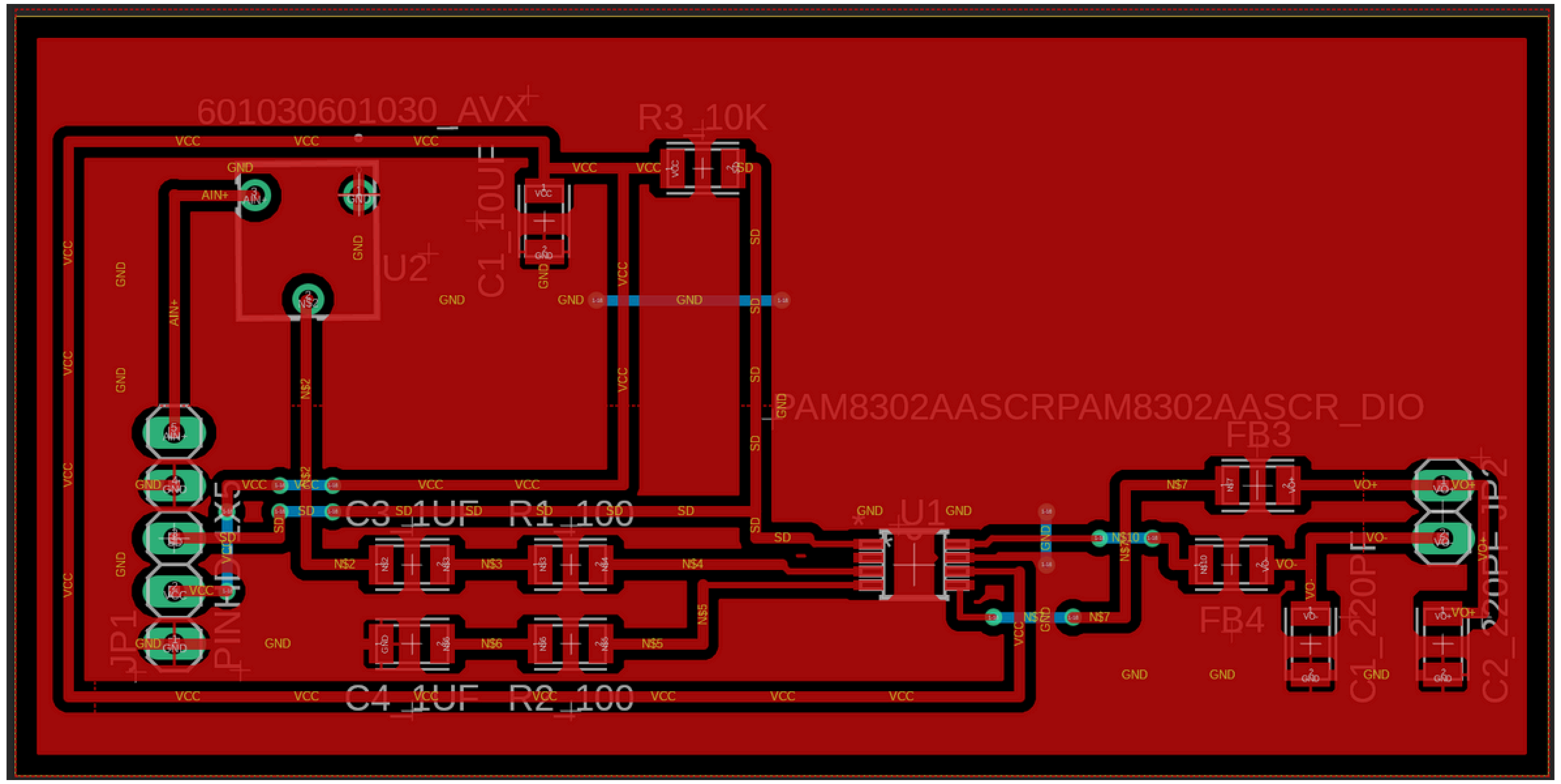


PCB

Audio Amplifier

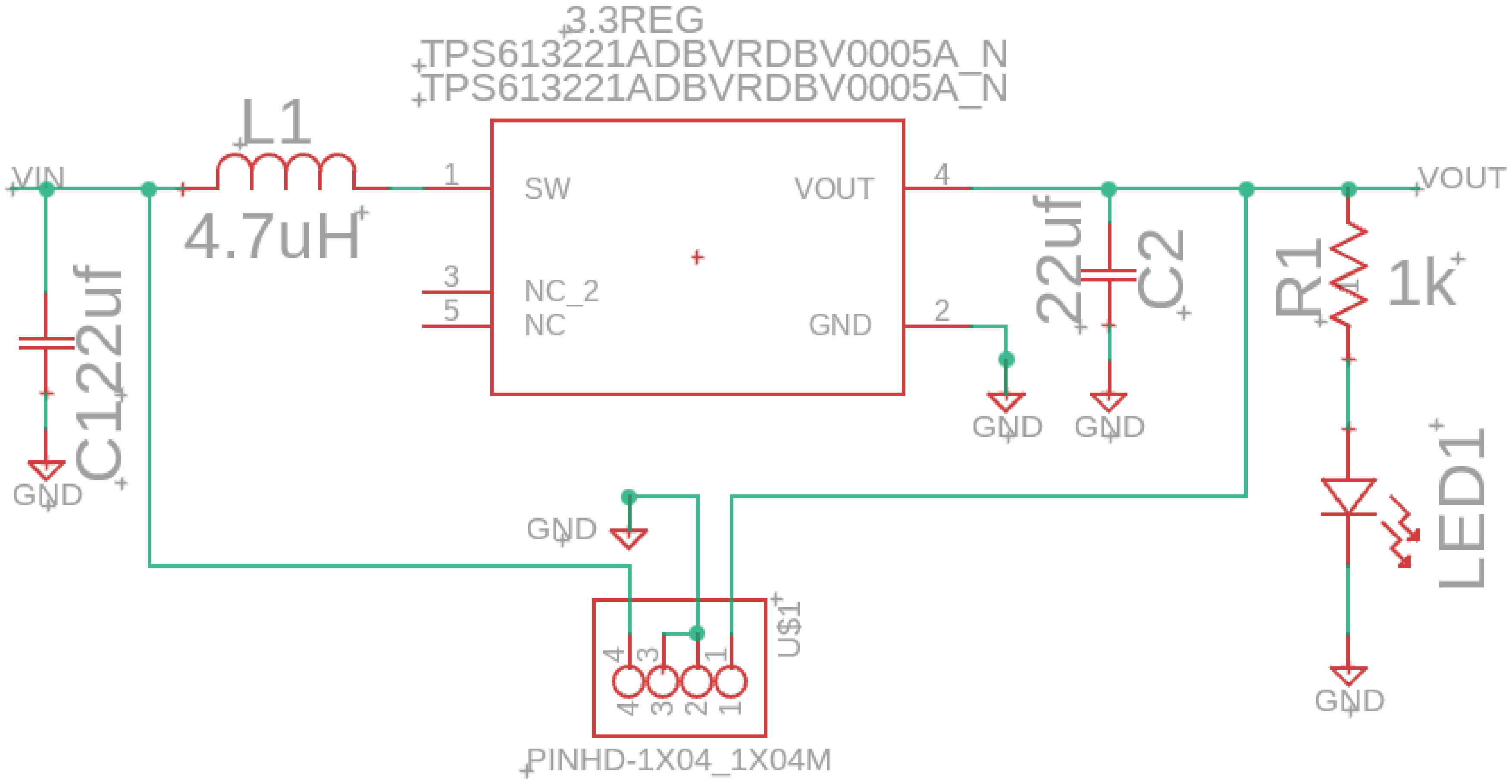


Schematic

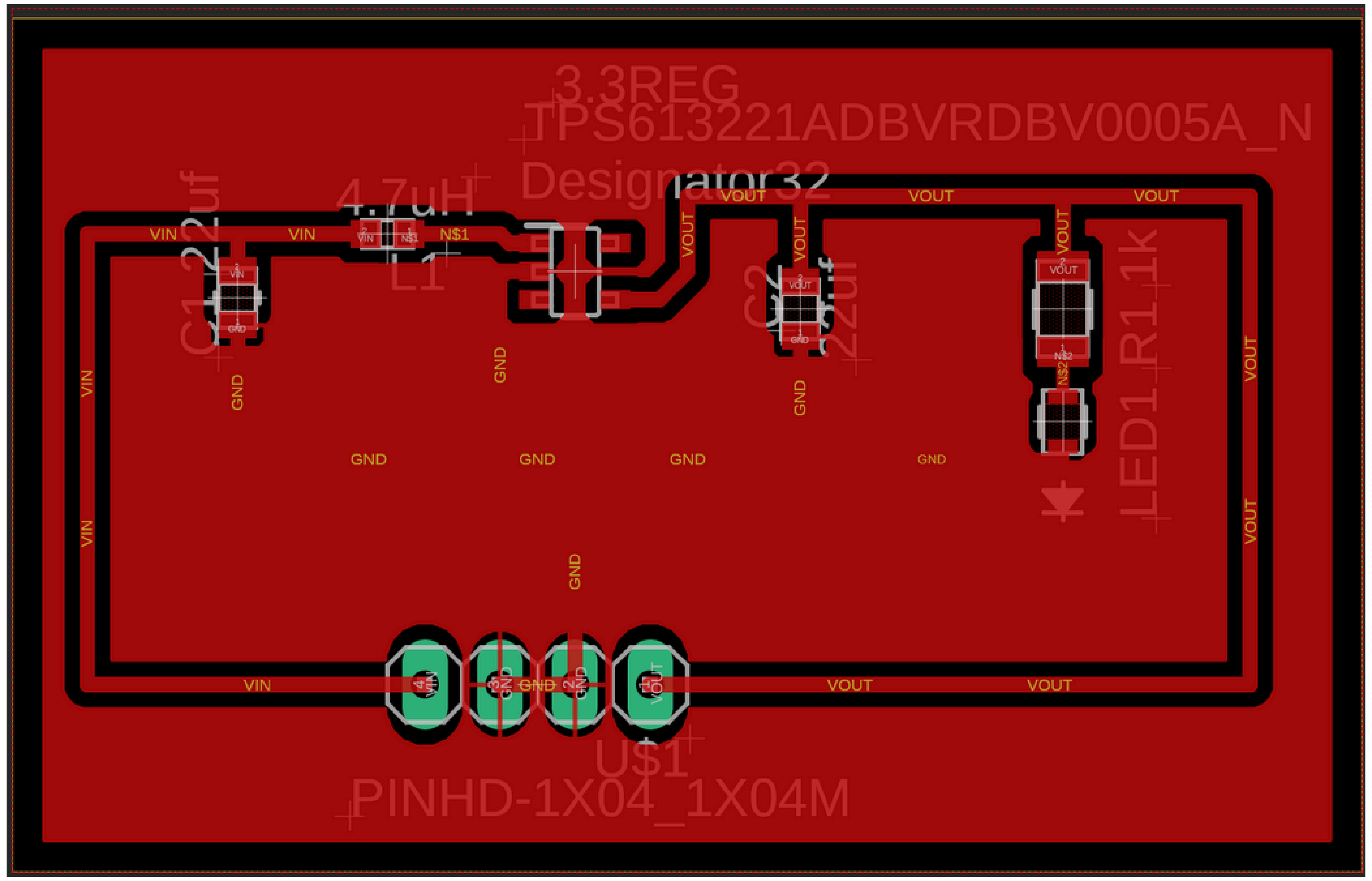


PCB

3.3V Regulator

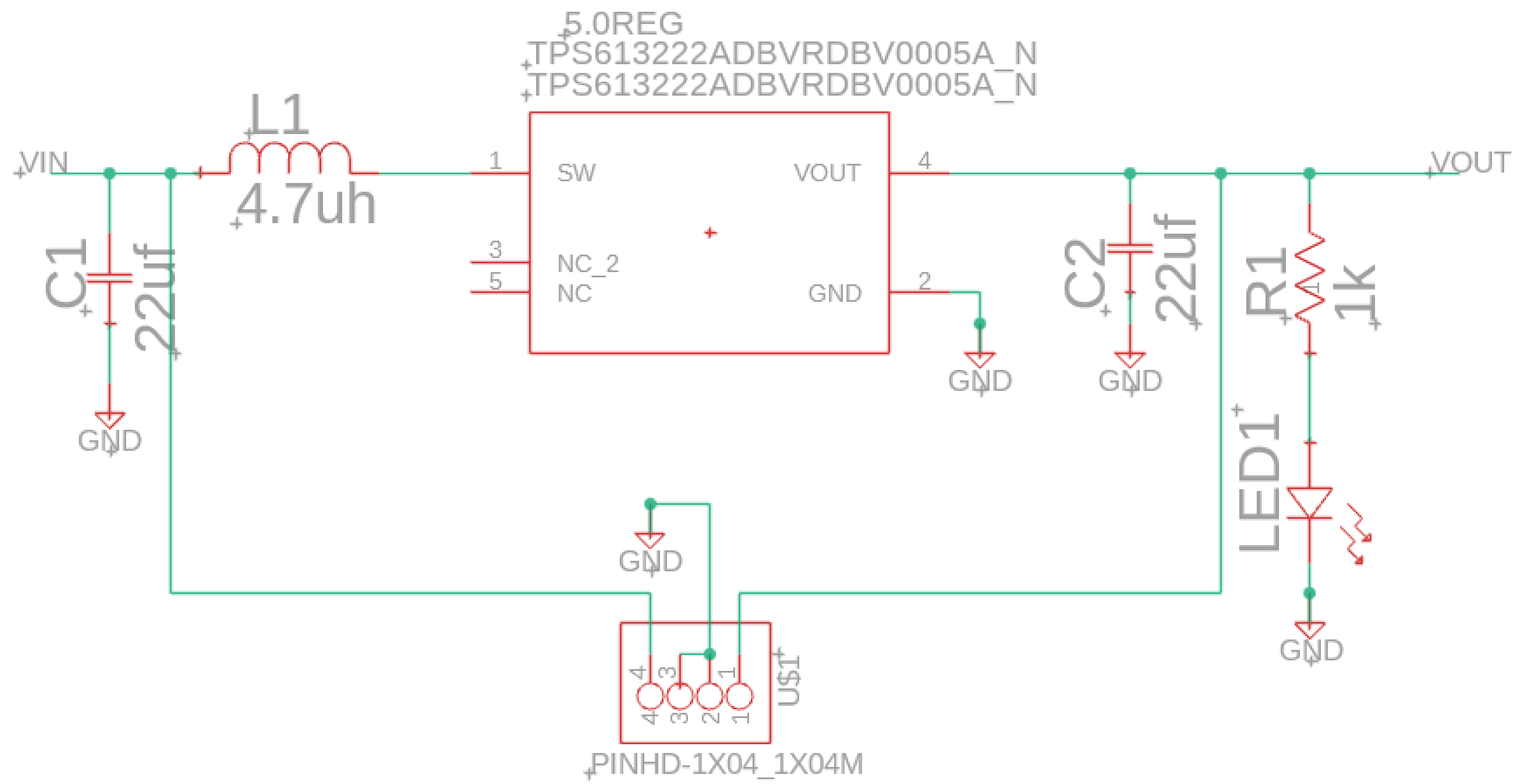


Schematic

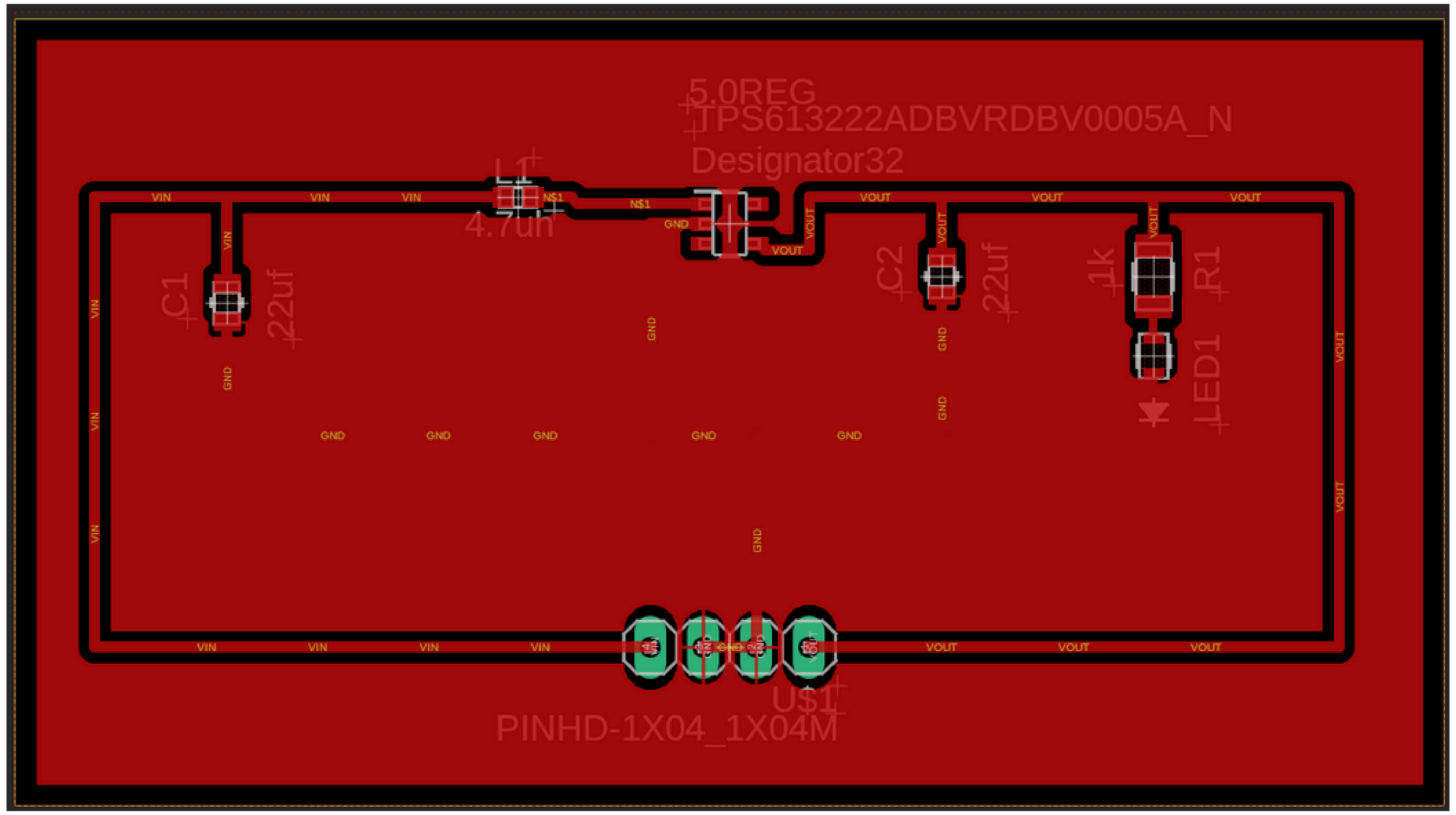


PCB

5V Regulator



Schematic



PCB

COMPARISON AND SELECTION OF SOFTWARE

Comparisons of Software Tools

Table 21: Summary of Software Tools

Software Tool	Purpose	Reason for Selection
ThorCam	Image capture for testing	Calibrating distortion patterns with DOE projection
Arduino IDE	Firmware development	ESP32 compatible, easily documented
ESP32 BSP	GPIO, camera, and network support	Hardware abstraction
Visual Studio Code	Advanced code editing and debugging	Debugging support
Canva.com	Diagram generation	Flowcharts, State diagram, Use Case Diagram
GitHub	Version control	History tracking, feature branching
PlatformIO	Advanced build system	Supports multiple targets and CI/CD-like builds

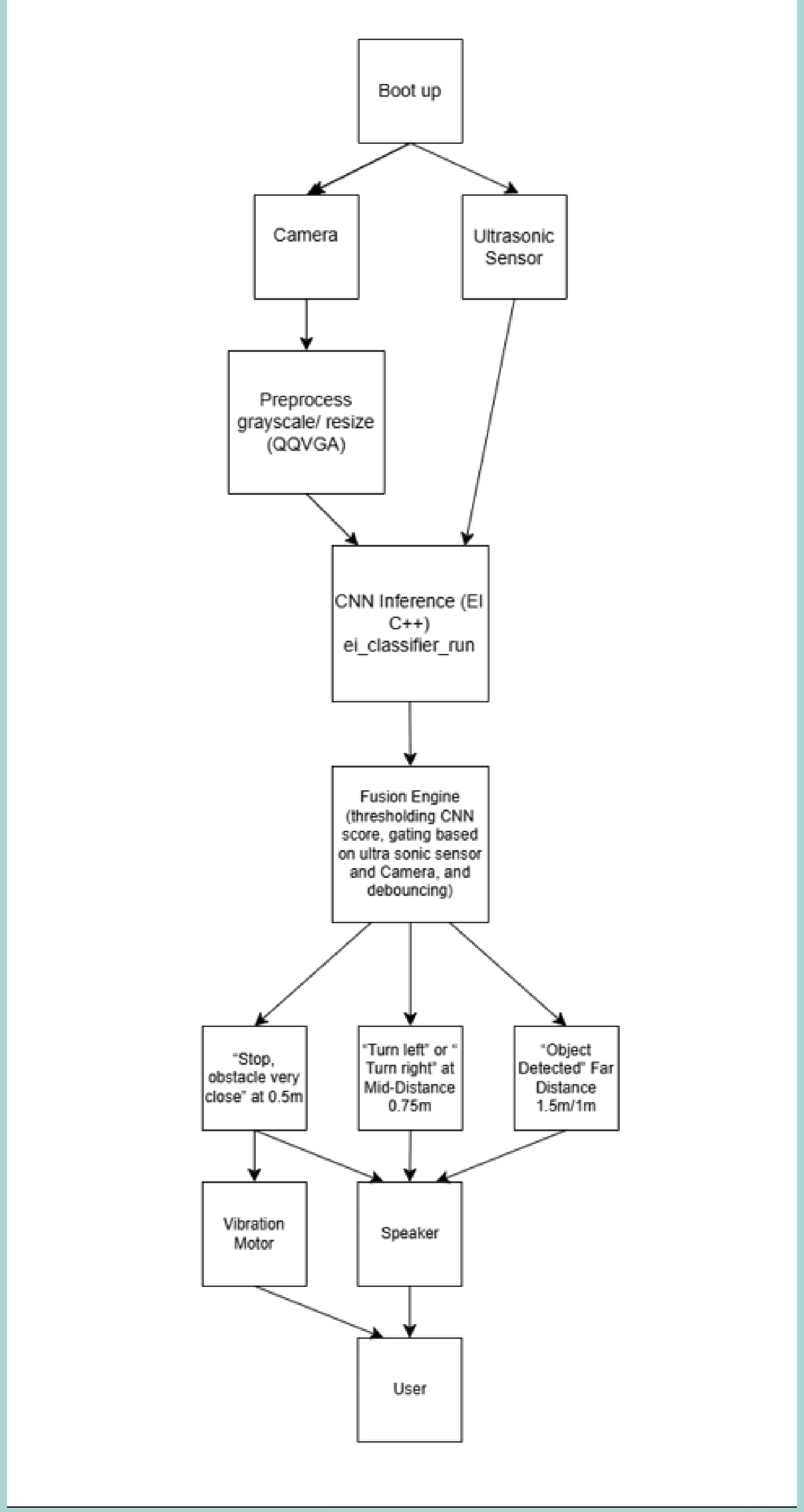
Libraries Used

Table 22: Core Software Libraries Used in Embedded Development

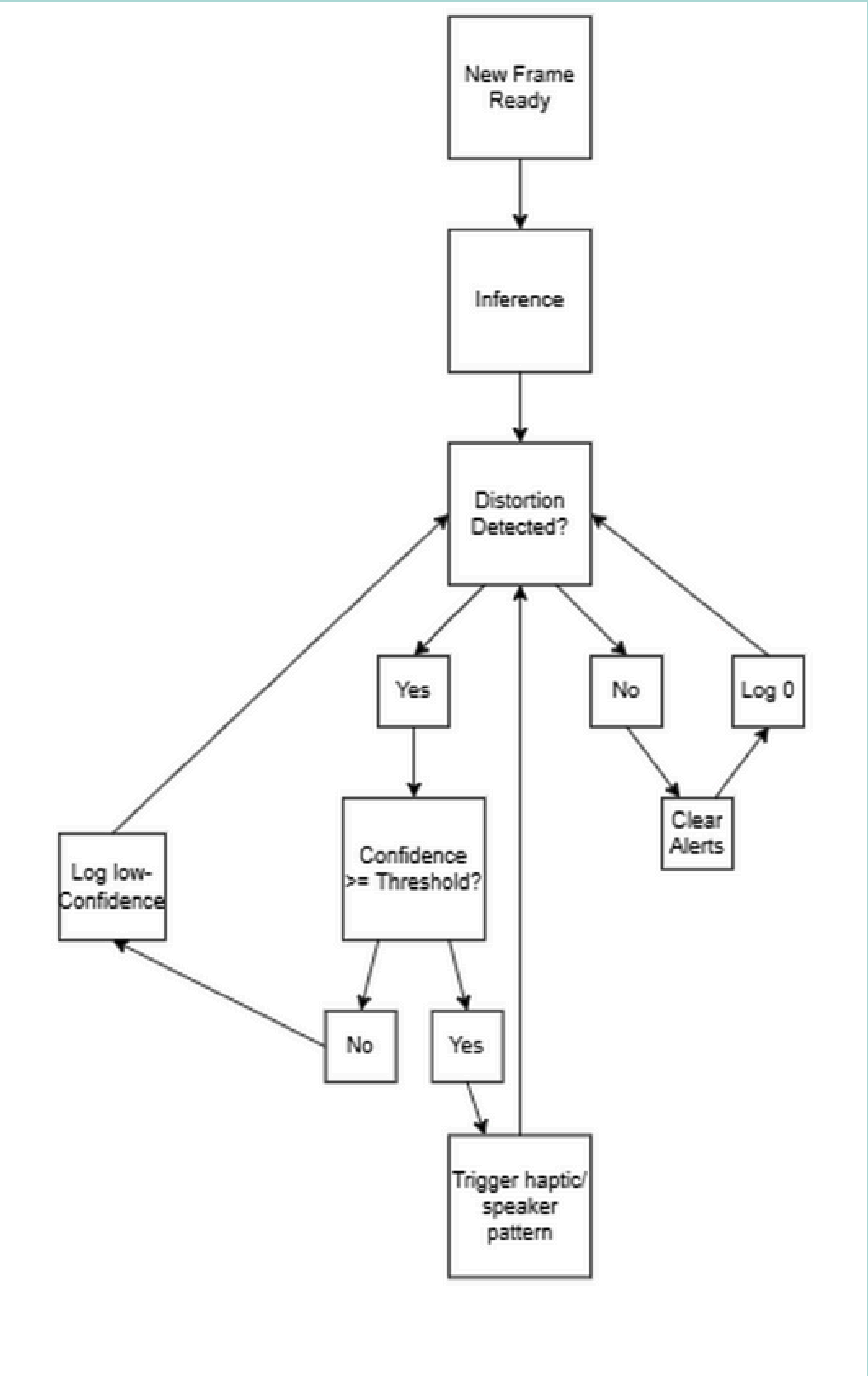
Library Name	Purpose	Relevance to Project
NewPing.h	Ultrasonic distance reading	Reads and averages data from HC-SR04
ESP32CAM.h	Camera management	Accesses frames from Thorlabs module
Wire.h	I2C communication	Interfaces with DRV2605L motor driver
Adafruit_DRV2605.h	Vibration motor control	Controls haptic feedback vibrations
tone()	Built-in function for audio feedback	Generate alerts using speaker

SOFTWARE DESIGN

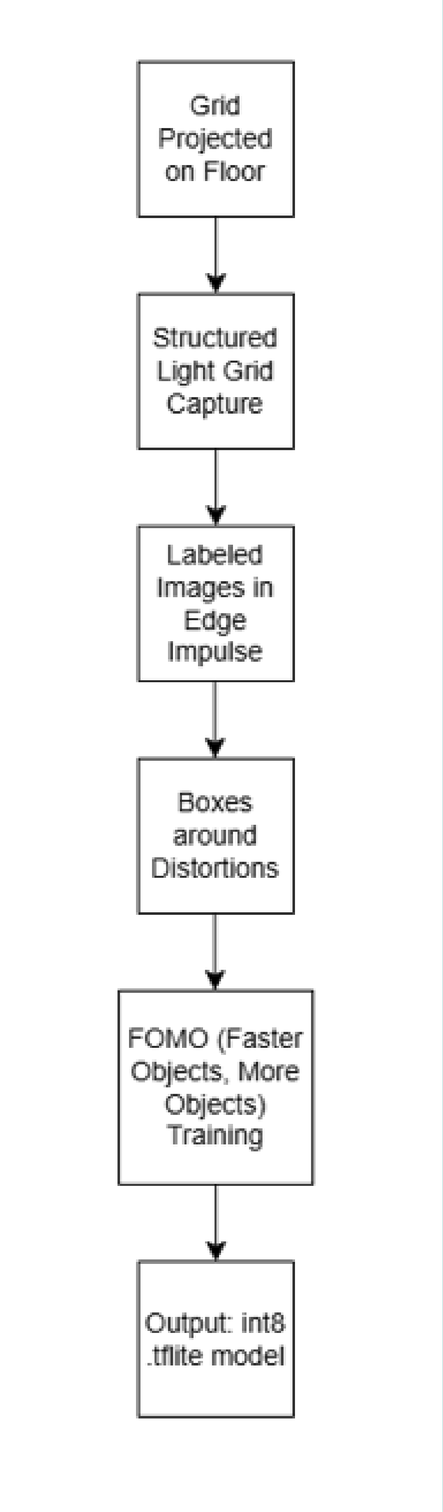
System Software Architecture/Dataflow



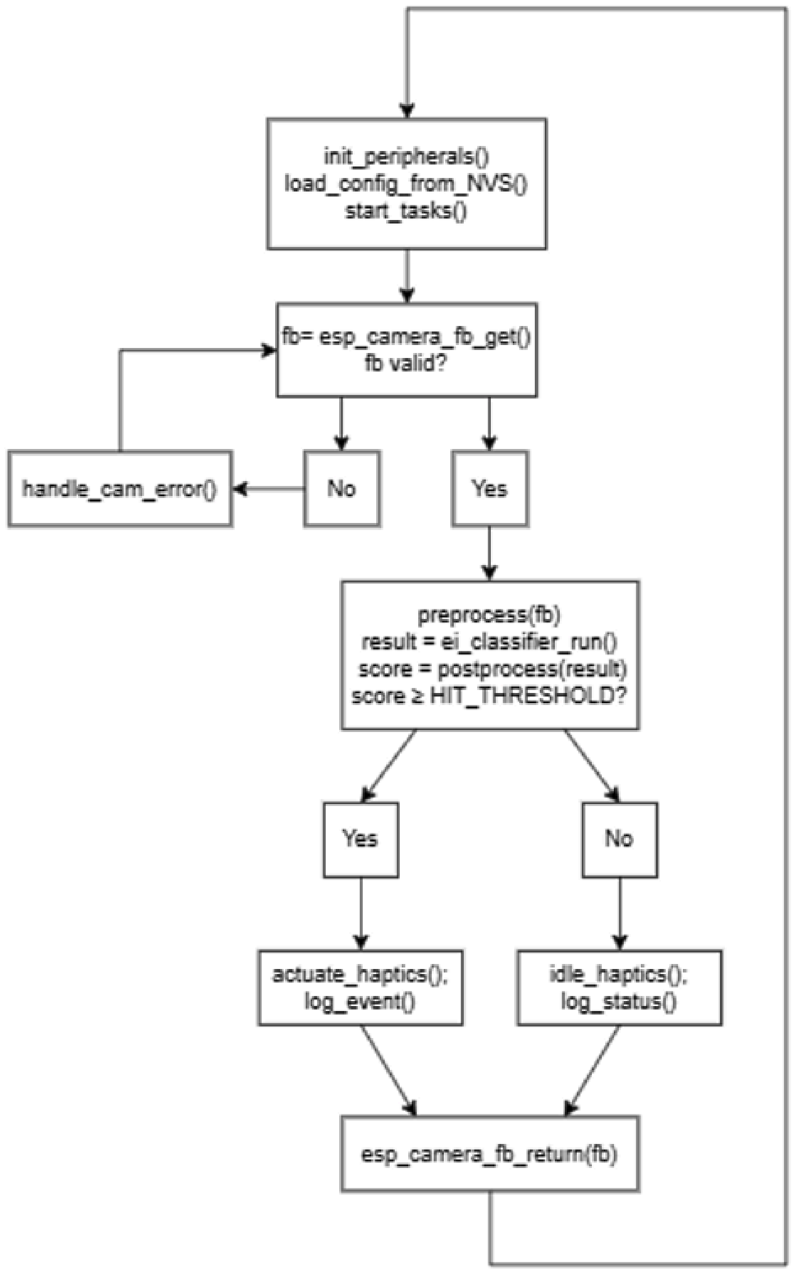
Detection Decision



Data Collection & Training Flowchart



Object Detection and Haptic Response Flowchart



PROTOTYPING AND TESTING

OPTICAL DESIGN CALCULATIONS

DOE "Detection Box" at 2 meters

$$Width\ 2xdxtan\left(\frac{\theta_H}{2}\right) = 2\ x\ 2\tan(20°) = 1.46m$$

$$Height\ 2xdxtan\left(\frac{\theta_V}{2}\right) = 2\ x\ 2\tan(10°) = 0.70m$$

Camera Sensor (OV2640 active array = 1600 x1200 pixels, 2.2μm *pitch*).

$$width\ 1600\ x\ 2.2\mu m = 3.52\ mm$$

$$height\ 1200x\ 2.2\mu m = 2.64mm$$

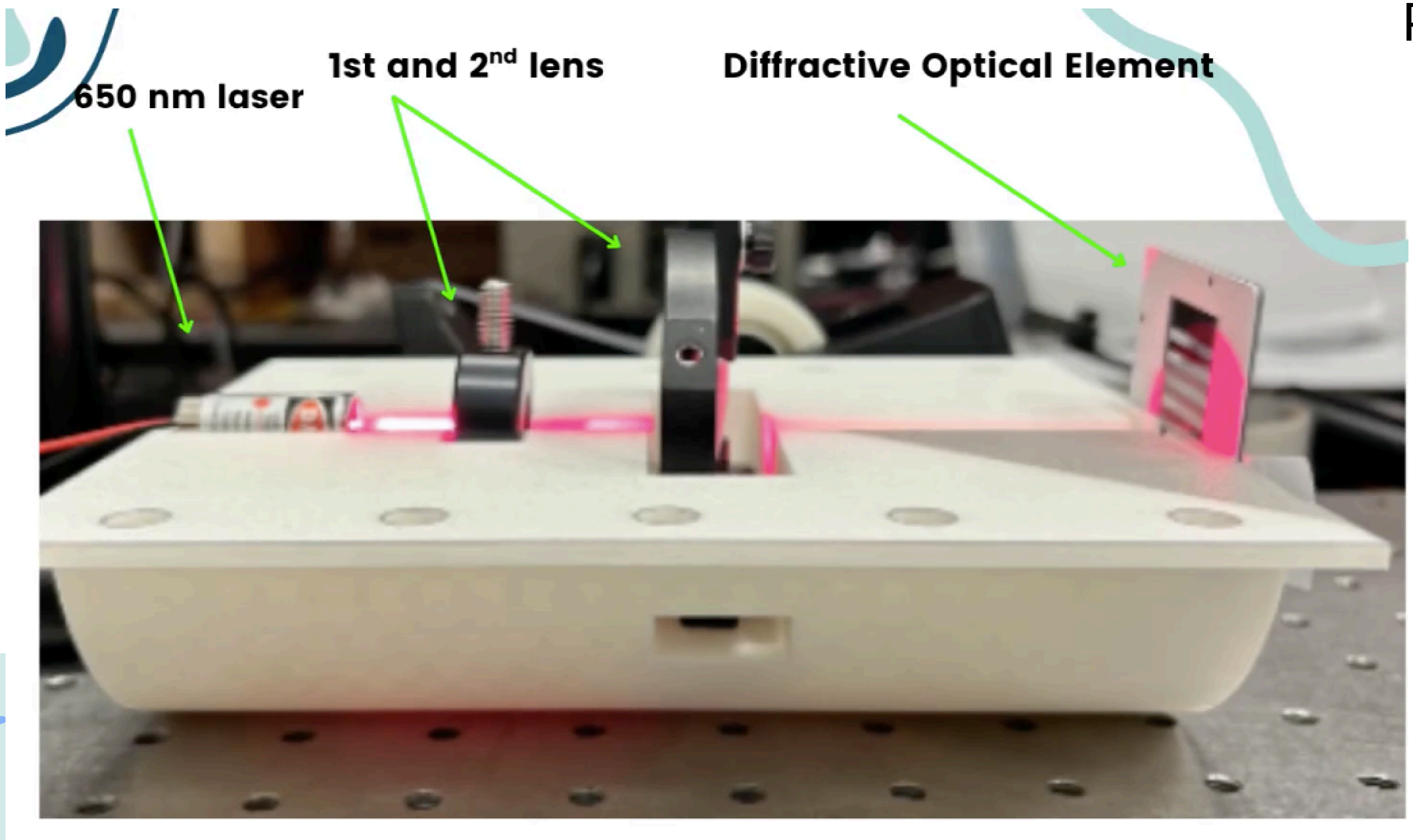
$$diagonal\ \sqrt{3.52^2 + 2.64^2} = 4.41mm$$

$$FOV = 2\arctan\left(\frac{sensor\ size}{2f}\right) = 2\arctan\left(\frac{4.41}{22.6}\right) = 81°$$

Horizontal scene width:

$2xtan\left(\frac{62°}{2}\right) = 2xtan(31°)x2x0.6018 = 1.2m$ falls within range of "detection box"

OPTICAL DESIGN COMPONENTS



Projected pattern at 2 meters with 650nm band pass filter

HARDWARE TESTING OF COMPONENTS

PCB Testing	Subsystem Testing	Integration Testing
Check for shorts/opens before powering	Ultra-Sonic Sensors	Connect subsystems
Apply power to see if the 3.3V and 5V regulators are stable	Vibration Motors	Run test code
Measure Current through each component	Audio Speaker	Check timing and latency

SOFTWARE TESTING

ESP32-S3-WROOM

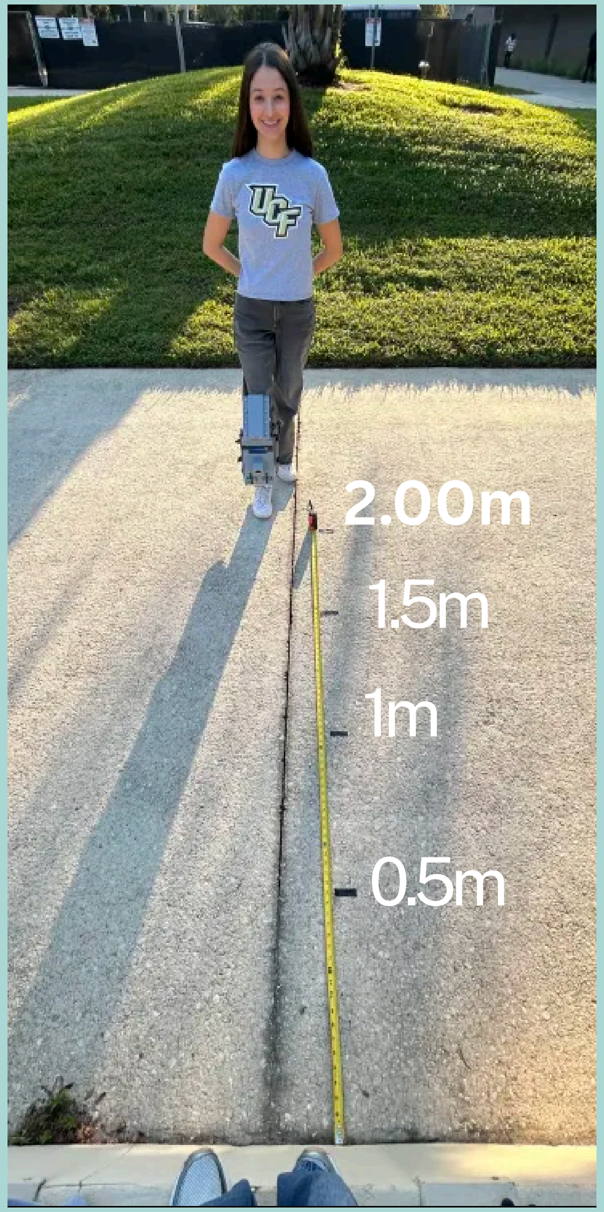
- Tested ultrasonic distance detection for left and right sides. (up to 2m)
- Verified LCD displays distance readings accurately.
- Confirmed DRV2605 vibration patterns trigger correctly at different distance zones.
- Checked DFPlayer audio alerts play safely without overlap.
- Ensured timing logic prevents repeated messages too quickly.

ESP32-CAM

- Verified camera capture functionality and image transmission.
- Tested integration with navigation and obstacle detection system.
- Checked camera feed updates reliably without lag.
- Validated communication between ESP32-CAM and S3 module

PERFORMANCE EVALUATION

Dectection Range



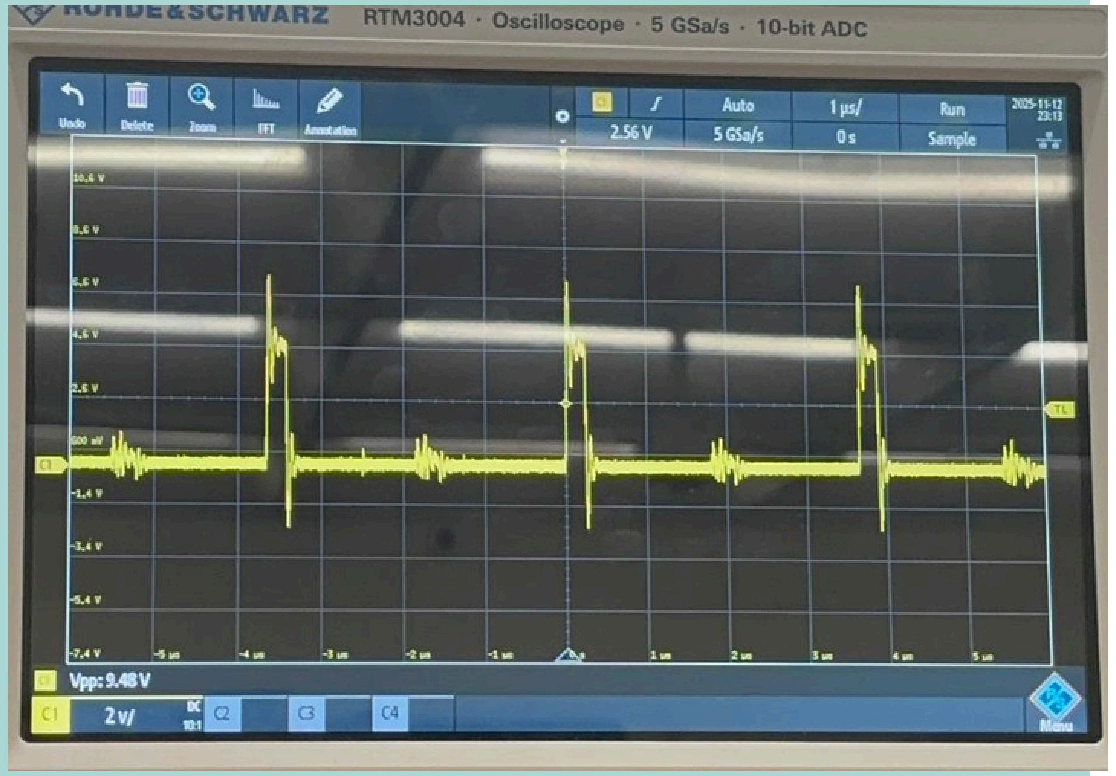
Trial #	Distance (m)	Distance (m)	Distance (m)	Distance (m)	Target	Detection
1	2	1.5	1	0.5	Wall	Yes
2	2	1.5	1	0.5	Wall	Yes
3	2	1.5	1	0.5	wall	yes

Accuracy

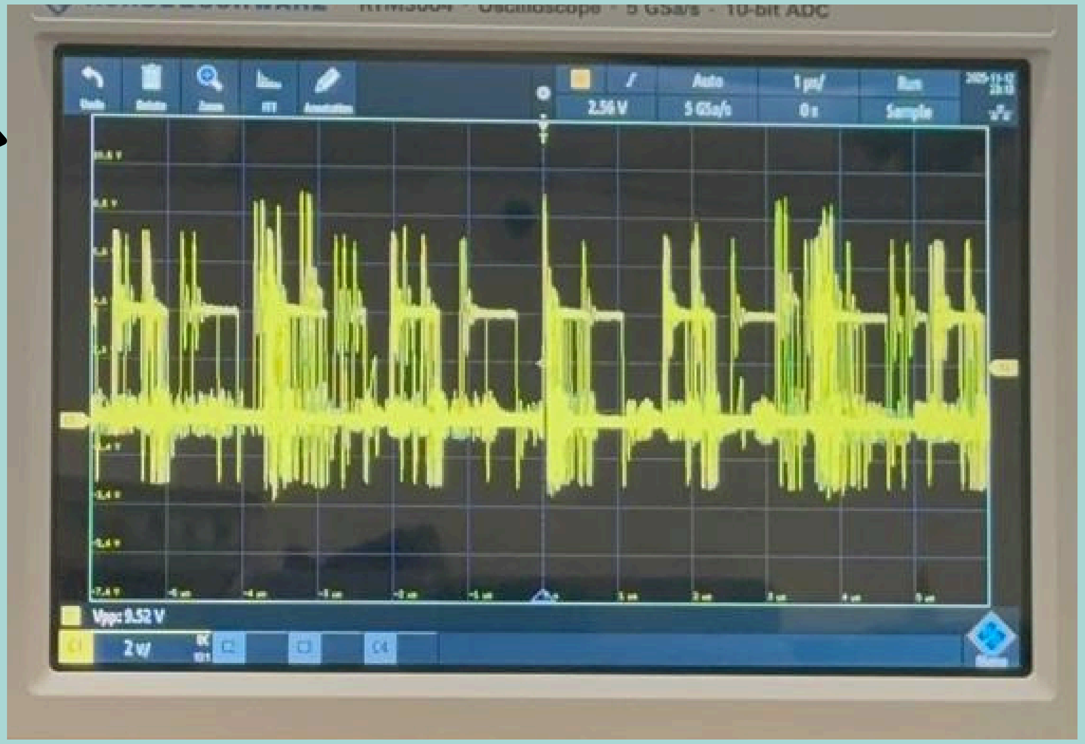
Test #	Expected Detection	Actual Detection	Accuracy (%)
1	wall	Detected	100%
2	person	Detected	100%
3	tree	Detected	90%
Average			97%

Response Time: both show 0.25-1us which is less than our required latency

No audio output



With Audio Output



CHALLENGES AND PROPOSED SOLUTIONS

Challenges

- We faced major difficulties during system integration, several ESP32-S3 chips were accidentally burned during testing and soldering.
- Our initial PCB designs had incorrect or oversized layouts, causing poor connections between components.
- Voltage regulators were also damaged due to wiring and power inconsistencies.

Proposed Solutions

- Implemented careful power testing and used current-limited bench supplies to prevent future chip damage.
- Revised PCB designs with correct dimensions, verified pin mappings, and improved layout spacing.
- Added protection circuits and ensured proper voltage regulation to maintain stable and safe power delivery.

ADMINISTRATIVE CONTENT

Budget

Component Name	Estimated Total ($)	Actual Total ($	Difference ($)	Status
ESP32-CAM (1 of 2 used)	$ 10.00	$ 15.08	-5.08	Over Budget
MB boards for the ESP32	$ 20.00	$ 17.49	2.51	Under Budget
1602 LCD Display	$ 5.00	$ -	5.00	Under Budget
Vibrational Motor (3x)	$ 6.00		6.00	Under Budget
Speaker	$ 10.00	$ 4.63	5.37	Under Budget
Battery	$ 30.00	$ 20.52	9.48	Under Budget
USB 2.0 Cable A Male to C Mal	$ 8.00	$ 3.05	4.95	Under Budget
Laser Module (2x)	$ 16.00	$ 23.78	-7.78	Over Budget
Lens	$ -	$ -	0.00	Under Budget
Diffractive Optical Elements (2	$ -	$ -	0.00	Under Budget
Shin guard	$ 10.00	$ 10.36	-0.36	Over Budget
Sock	$ 15.00	$ 11.41	3.59	Under Budget
PCB	$ 200.00	$ 180.00	20.00	Under Budget
DigiKey Parts (2 orders total)	$ 100.00	$ 90.10	9.90	Under Budget
3D Filament	$ 40.00	$ 25.00	15.00	Under Budget
SD cards	$ 10.00	$ 9.56	0.44	Under Budget
cones	$ 5.00	$ 3.00	2.00	Under Budget
bolts	$ 10.00	$ 9.05	0.95	Under Budget
Female to male A cable	$ 12.00	$ 10.64	1.36	Under Budget
50MW Laser	$ 20.00	$ 18.88	1.12	Under Budget
250MW Laser	$ 30.00	$ 30.00	0.00	Under Budget
DF Mini Player	$ 10.00	$ 10.54	-0.54	Over Budget
total	$ 567.00	$ 493.09		

Work Distribution

- Coordinate team meetings and ensure milestones are met
- Oversee PCB testing once boards arrive
- Completed Edge Impulse training and working on the SW main code
- Verify hardware interfaces
- Develop bench tests for subsystems

- In charge of PCB schematics and layouts for accuracy before fabrication
- Handle board to board connections
- Assist with hardware integration and assembly
- Assist with developing bench tests for subsystems

- Characterize optical components
- Optimize camera/laser alignment for accurate detection and data capture.
- Support firmware/software team with image/signal analysis integration.
- Validate optical subsystem performance under different environmental conditions

Next Steps:

- Finalize team documentation
- Update and upload documentation to website

If we had more time:

- Make our system more compact and lightweight
- Improve software for user interface

Thank you!

PRESENTED BY GROUP 5