SIGHTSENSE

A SMART HAPTIC ALERT OBSTACLE DETECTION SYSTEM FOR THE VISUALLY IMPAIRED

Critical Design Review

PRESENTED BY: GROUP 5

Meet the Team

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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.

Goals – Basic

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 users to easily wear it over different types of shoes within in 30 seconds.

Goals - Advanced

Enhance the user experience by incorporating a forward-facing camera module capable of capturing real time environment mapping and identifying at least four object categories (wall, door, person, and tree).

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.

Incorporate a voice guidance system that delivers clear, spoken instructions (e.g., Obstacle detected) around obstacles using audio output, with latency under <1 second.

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 60dB), ensuring consistent detection for indoor, outdoor, and low light with background noise.

Goals - Stretch

Expand shoe 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 within the insole, to allow visually impaired users to quickly signal for help by sending their location to an emergency contact in <15 seconds.

Objectives

To develop a strap on device that will reliably detect obstacles and provide real-time haptic and audio feedback, ensuring safety for the visually impaired users.

01

Obstacle detection
Ultrasonic sensors detect object within 2m; LCD to display distance; 3D light structure with camera.

02

Usability & Power
Strap on module that attaches in <30s; rechargeable battery that supports 6-10 hours of daily use; tested indoors/outdoors.

03

Enhanced Guidance
Haptic feedback, voice guidance (<1s delay), reliable in different settings, ≥90% object detection.

04

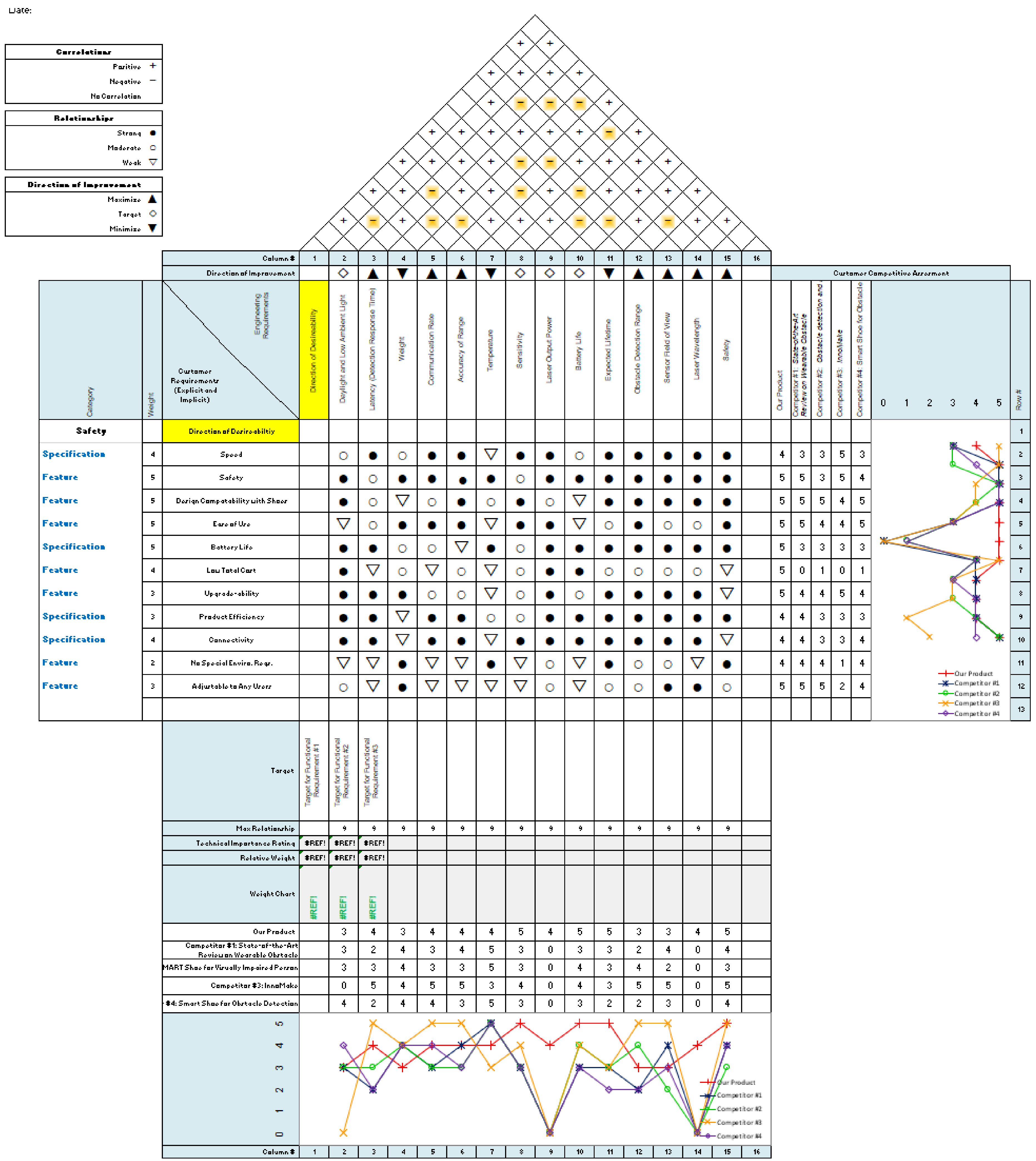
Safety & Accessibility
Fall detection + GPS emergency alert, SOS pressure sensor, GPS navigation with preset destinations, bilingual voice feedback.

Engineering Requirements

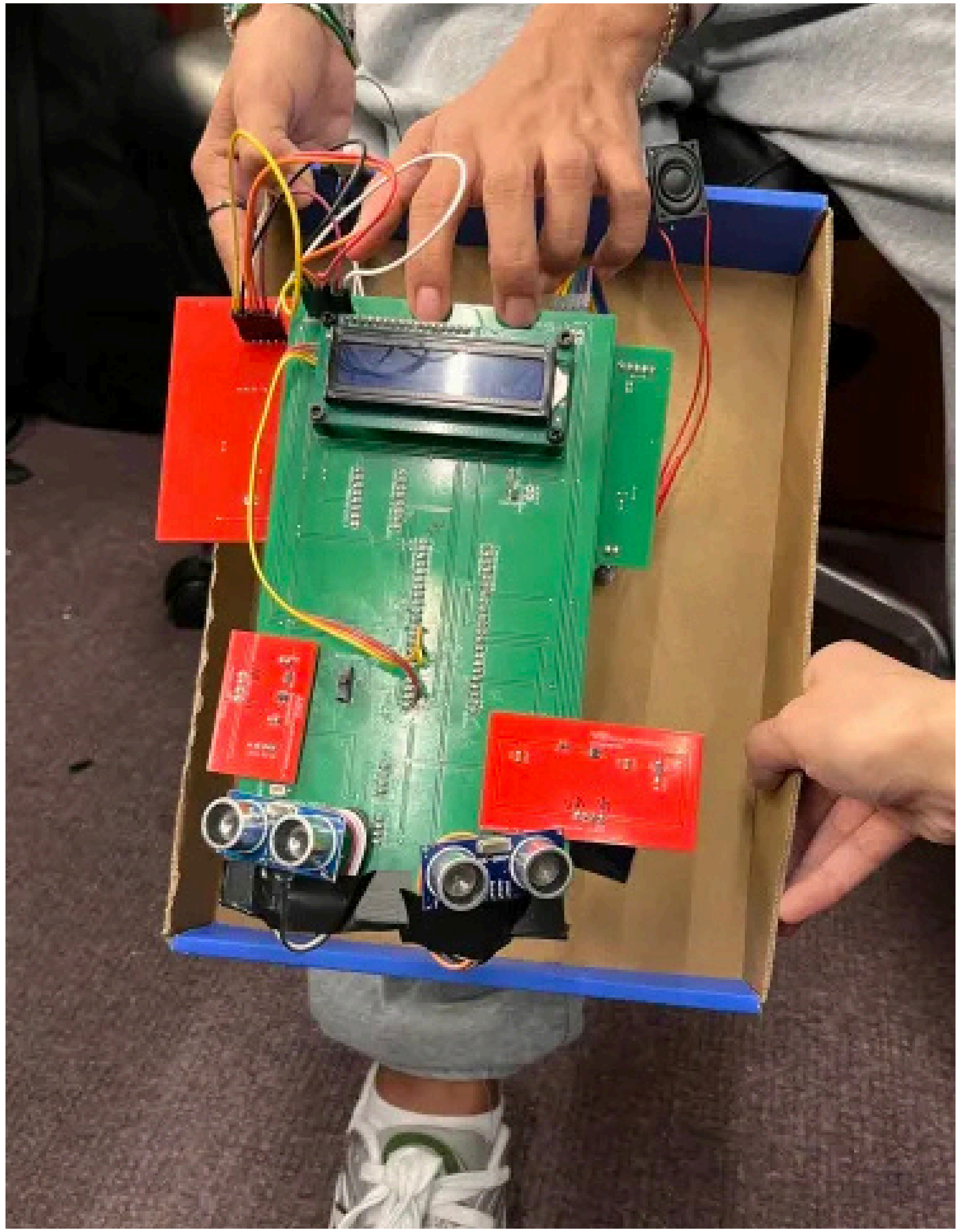
Engineering Requirement	Specification
High detection accuracy for multiple forms of obstacles (i.e., people, walls, trees, curbs, ditches/drop-offs, and steps).	≥ 90%
Distance of obstacle detection in front of the user should be significant.	≤ 2 meters
Immediate response time between obstacle detection systems (i.e., structured light and ultrasonic) for real time alerts.	≤ 250 milliseconds
Battery life for user should last a certain amount of time.	6-10 hours
Field of View needed to ensure proper range for obstacle detection.	60°
Obstacle detection system must work without interference from daytime ambient light to low light.	≤ 85%
Device needs to be able to run on a low power mode.	≤ 90%
Device needs to be wearable and light weight.	≤ 5 lbs

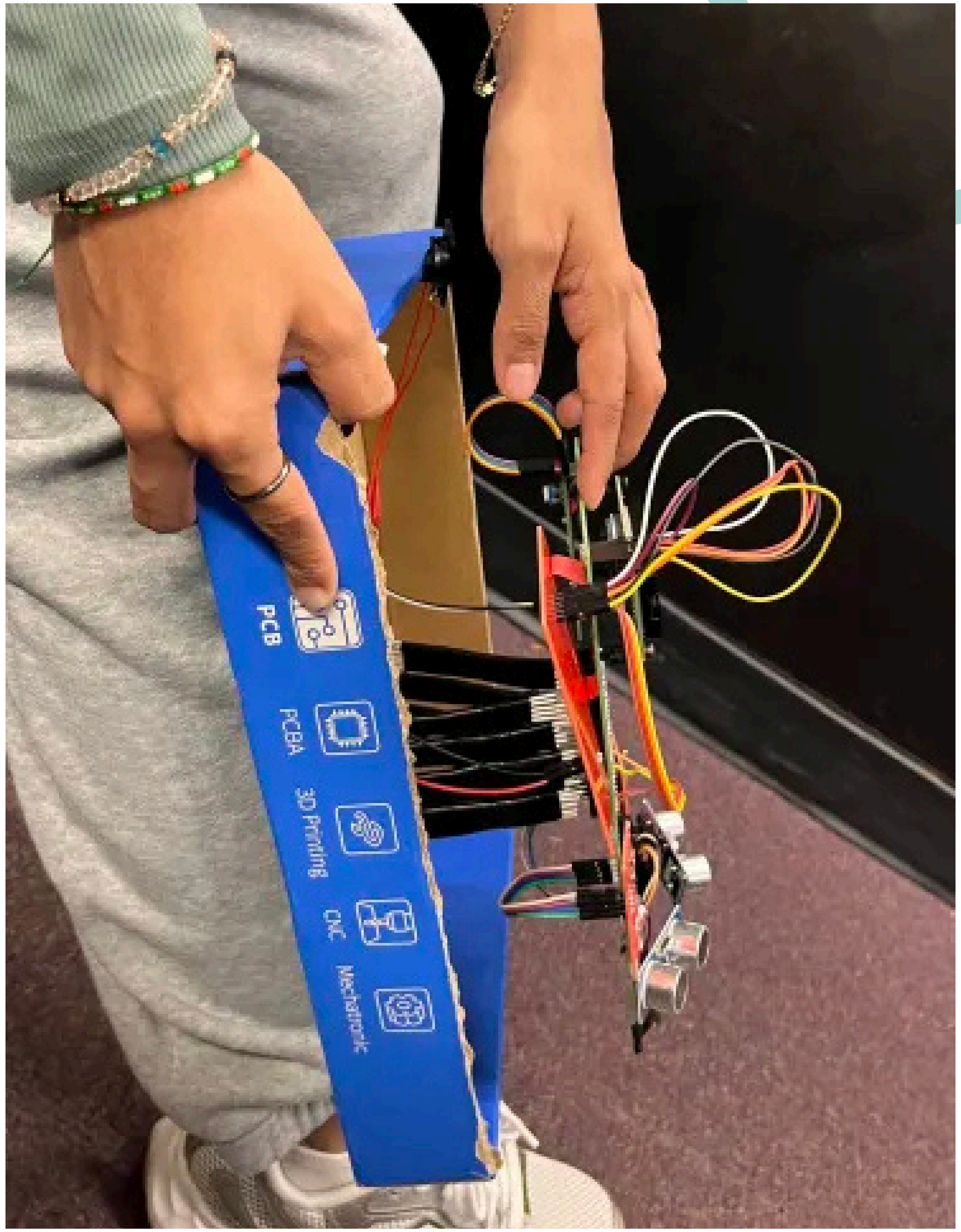
***Highlighted section of table is for the overall system.**

House of Quality

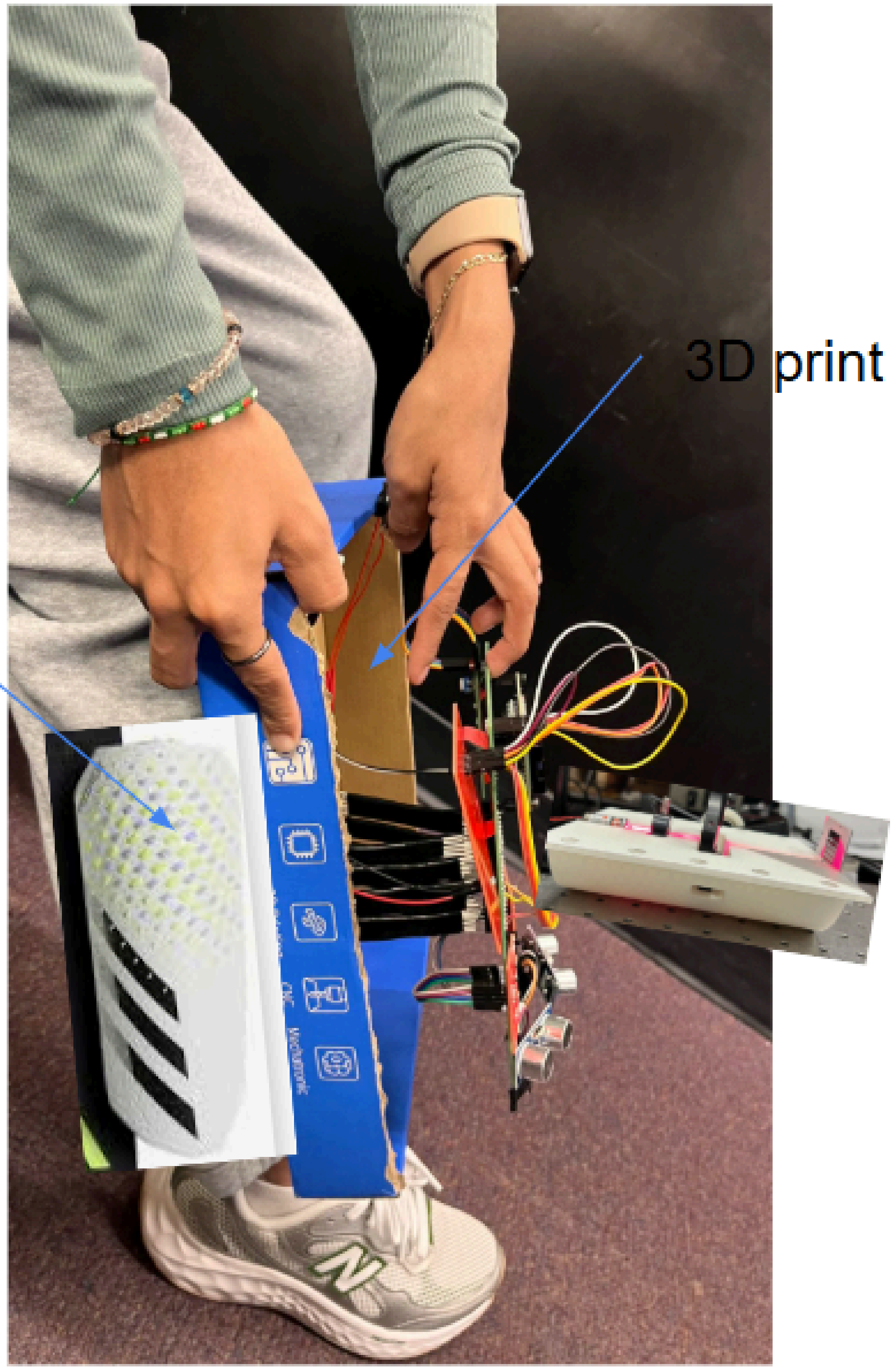


SHINGUARD PROTOTYPE





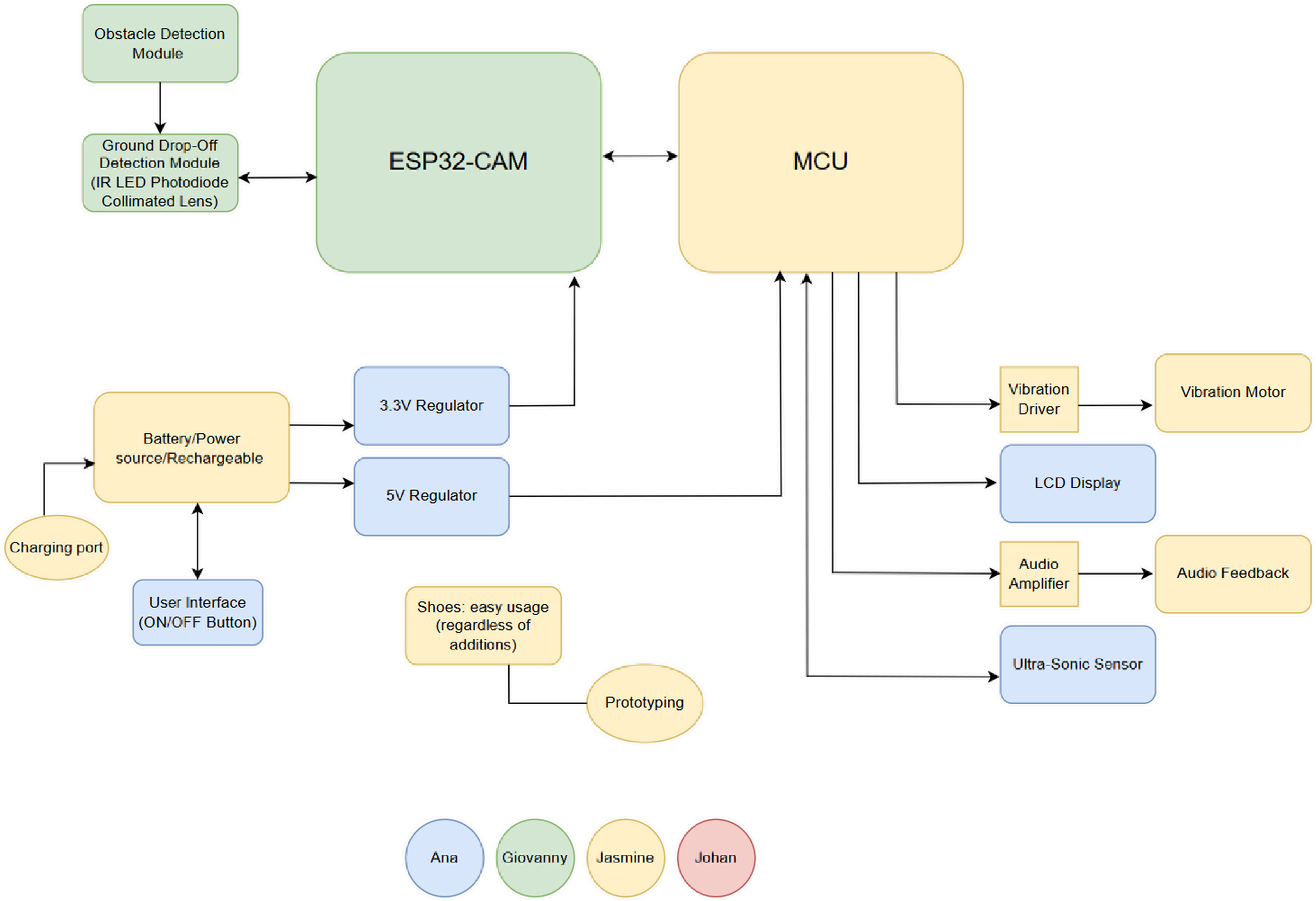
FINAL PROTOTYPE DESIGN



HARDWARE

HW Design

Block Diagram



COMPARISON AND SELECTION OF HARDWARE

Microcontroller Unit (MCU) Selection

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

MCU Selection

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

Laser Selection

Part Name	Waveleng th (nm)	Output Power	Beam Shape	Driver Included	Price
Lasermate LDM-655-04	650nm	4mw	Elliptical	Yes (TTL Modulated)	$42.00
Amazon Red Laser Module	650nm	5mw	Circular	Yes	$10.99
Thorlabs CPS635R	635nm	0.6mw	Circular	Yes	$78.00

Lens Selection

Lens	Focal Length	Field of View	Mount Type	Lens Type	Distortio n	Cost
2.1 mm Wide angle M12	2.1mm	160 degree	M2	Wide angle glass	High barrel distorton	$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

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

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

Vibration Motor Selction

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

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

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

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

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

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

5.0V Regulator

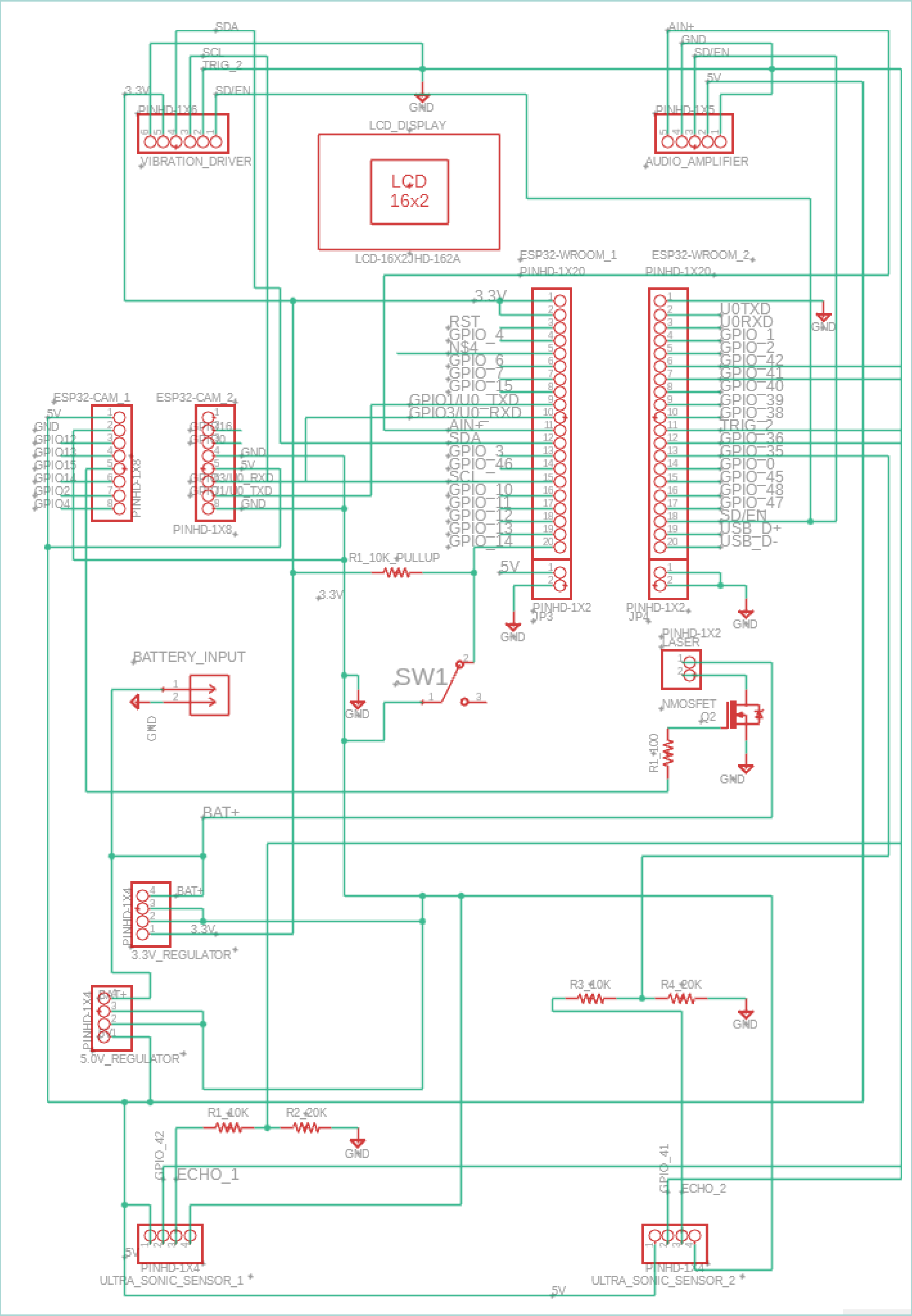
Components	TPS613222	HiLetgo DC-DC Step Up Booster Converter	AliExpress Mini Boost
Input Voltage	0.9-5.5V	2-24V	2-24V
Output Voltage	Fixed 5V	Adjustable up to ~28V	Adjustable up to ~28V
Max Output Current	1.2A peak, ~500-600mA continuous	~1-2A (depends on cooling)	~1A
Key Features	Designed to spec, stable, 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)

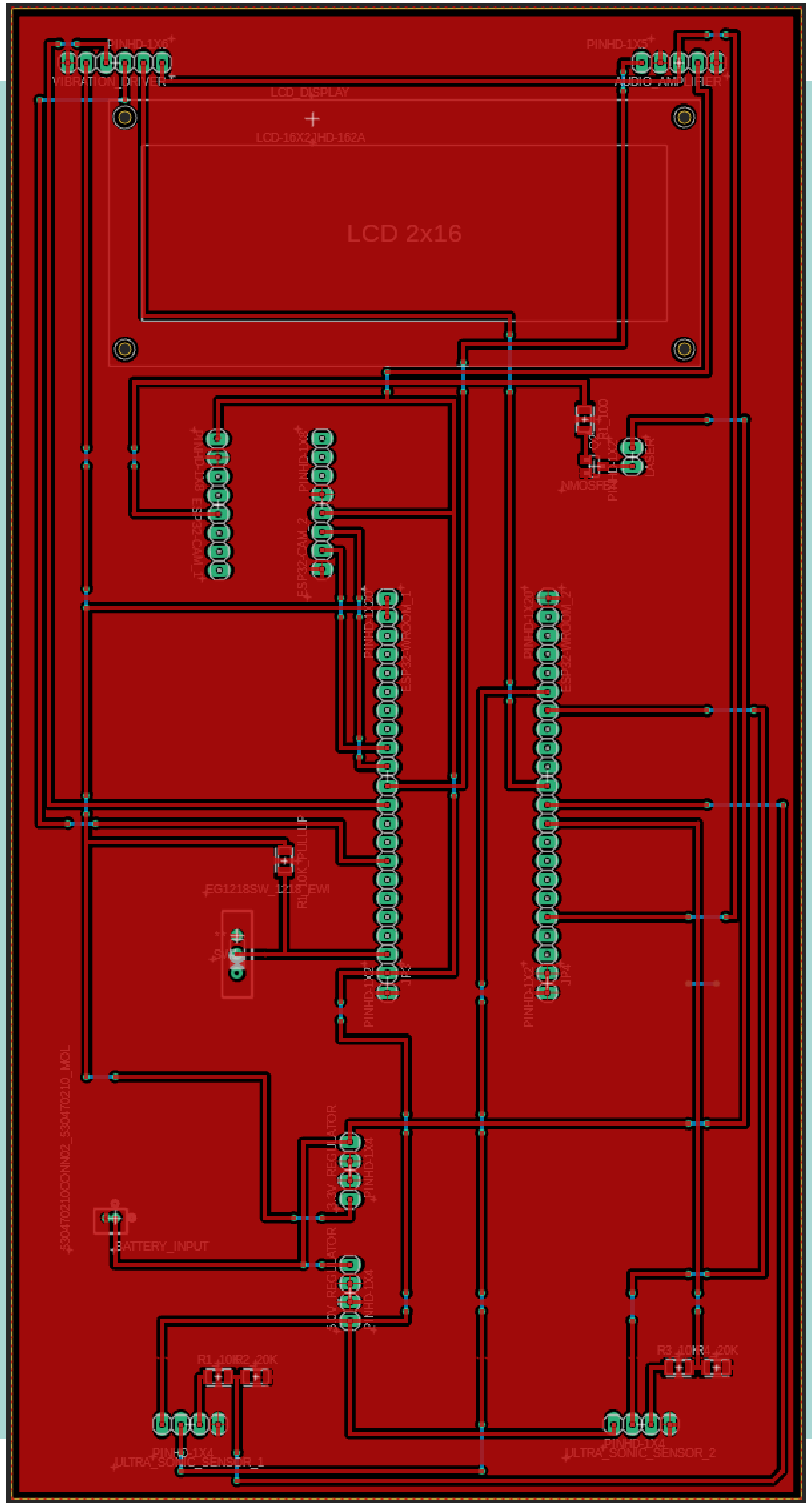
Power Flow

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	-

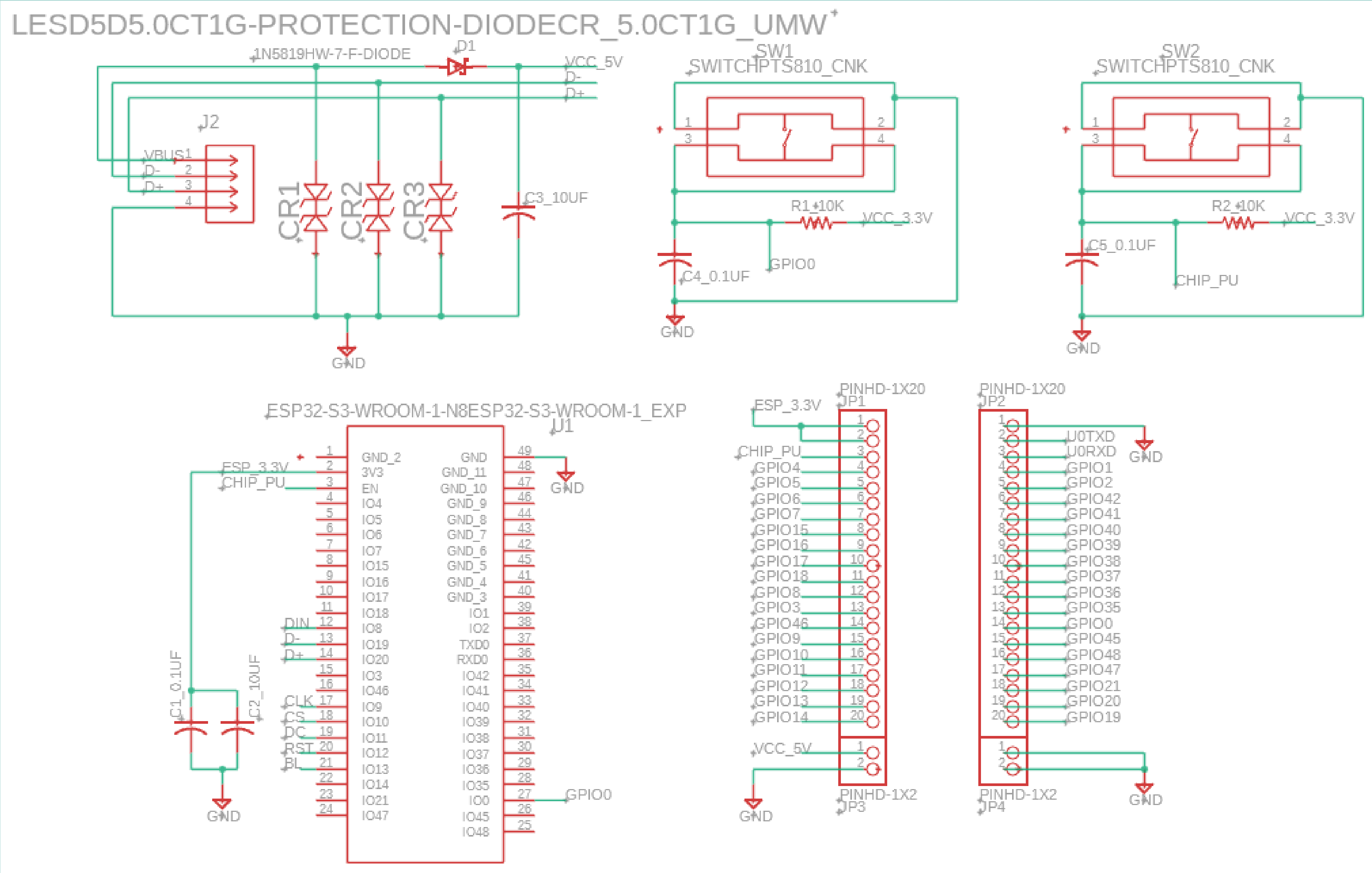
SCHEMATICS AND PCB'S

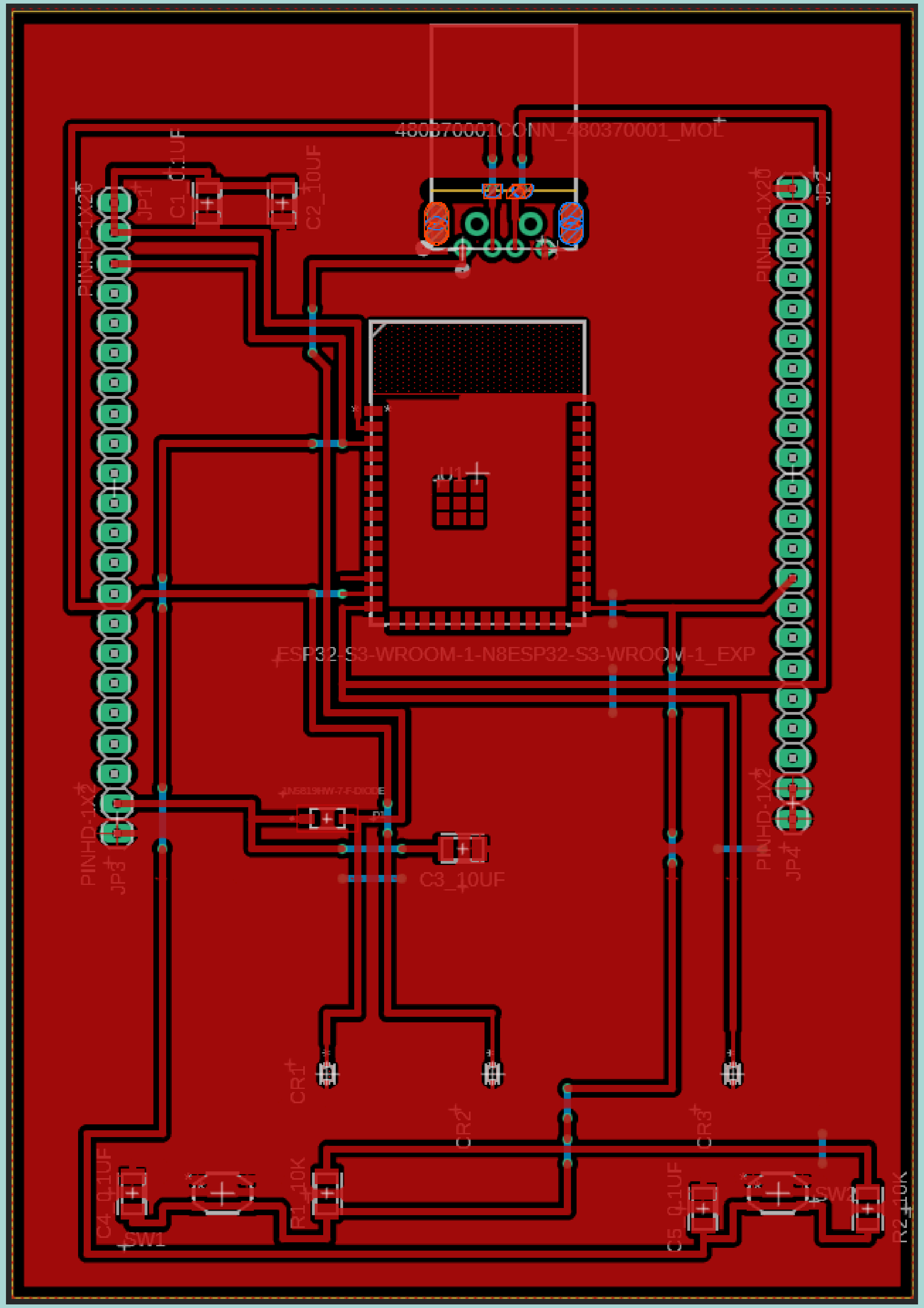
Main Board


VIBRATION_DRIVER
LCD_DISPLAY
LCD
16x2
LCD-16X2 HD-162A
AUDIO_AMPLIFIER
ESP32-WROOM_1
ESP32-WROOM_2
ESP32-CAM_1
ESP32-CAM_2
BATTERY_INPUT
SW1
NMOSFET
LASER
BAT+
3.3V_REGULATOR
5.0V_REGULATOR
ECHO_1
ECHO_2
ULTRA_SONIC_SENSOR_1
ULTRA_SONIC_SENSOR_2

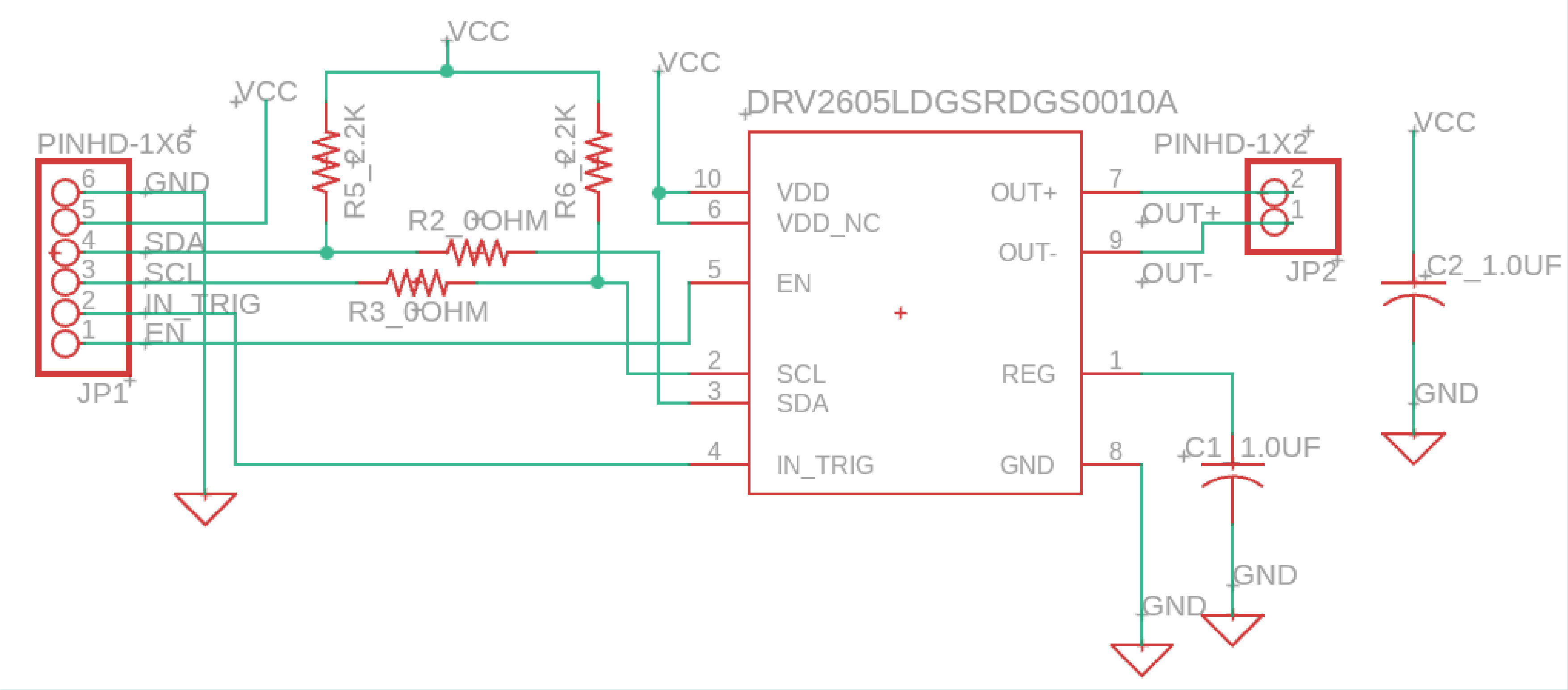

VIBRATION_DRIVER
AUDIO_AMPLIFIER
LCD_DISPLAY
LCD 2x16
BATTERY_INPUT
ULTRA_SONIC_SENSOR_1
ULTRA_SONIC_SENSOR_2

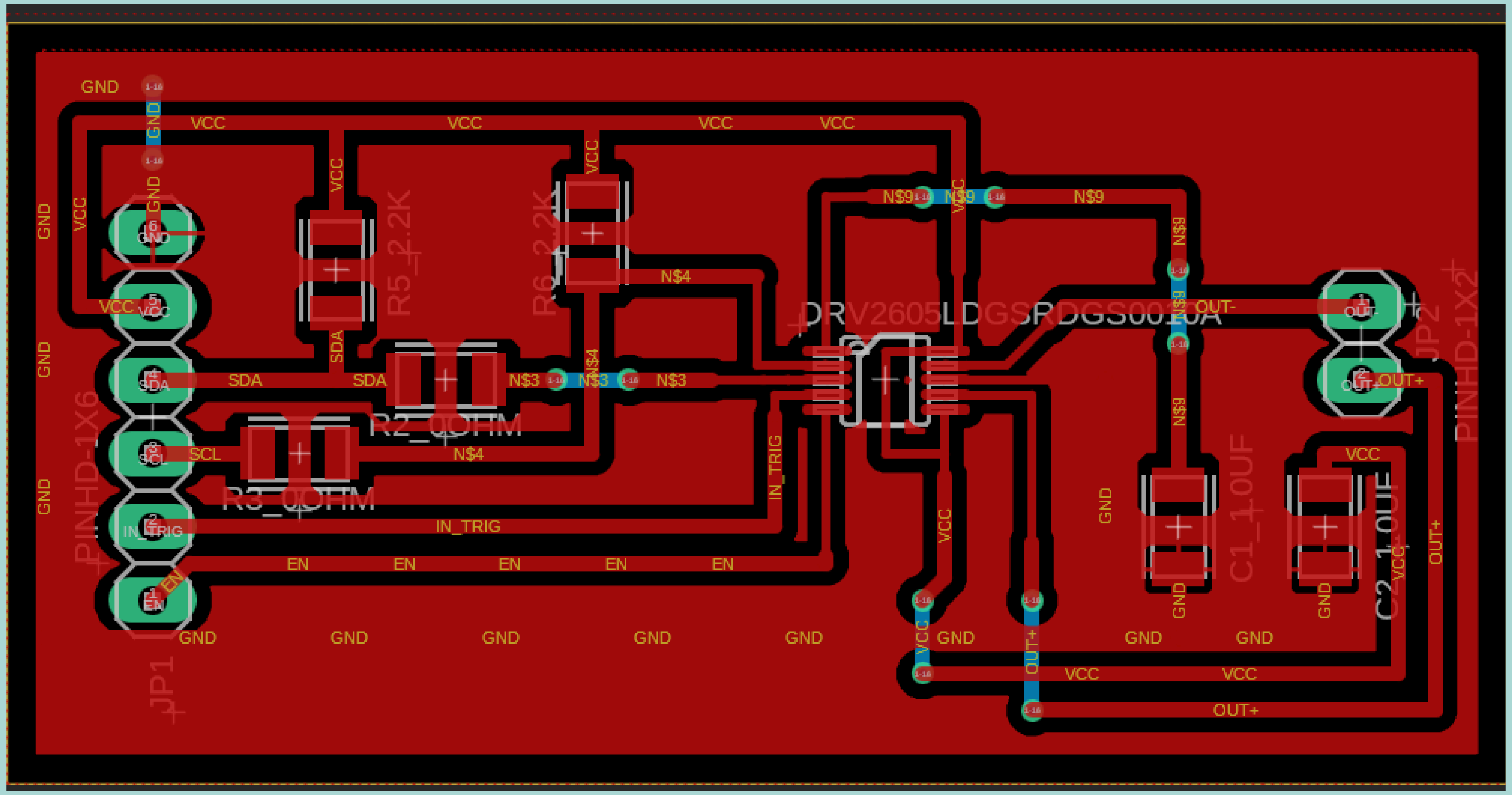
MCU


LESD5D5.0CT1G-PROTECTION-DIODECR_5.0CT1G_UMW
1N5819HW-7-F-DIODE
D1
VCC_5V
D-
D+
J2
VBUS
CR1
CR2
CR3
C3_10UF
GND
SW1
SWITCHPTS810_CNK
R1 10K
VCC_3.3V
C4_0.1UF
GPIO0
SW2
SWITCHPTS810_CNK
R2 10K
C5_0.1UF
CHIP_PU
ESP32-S3-WROOM-1-N8ESP32-S3-WROOM-1_EXP
U1
ESP_3.3V
C1_0.1UF
C2_10UF
PINHD-1X20
JP1
JP2
U0TXD
U0RXD
PINHD-1X2
JP3
JP4
VCC_5V

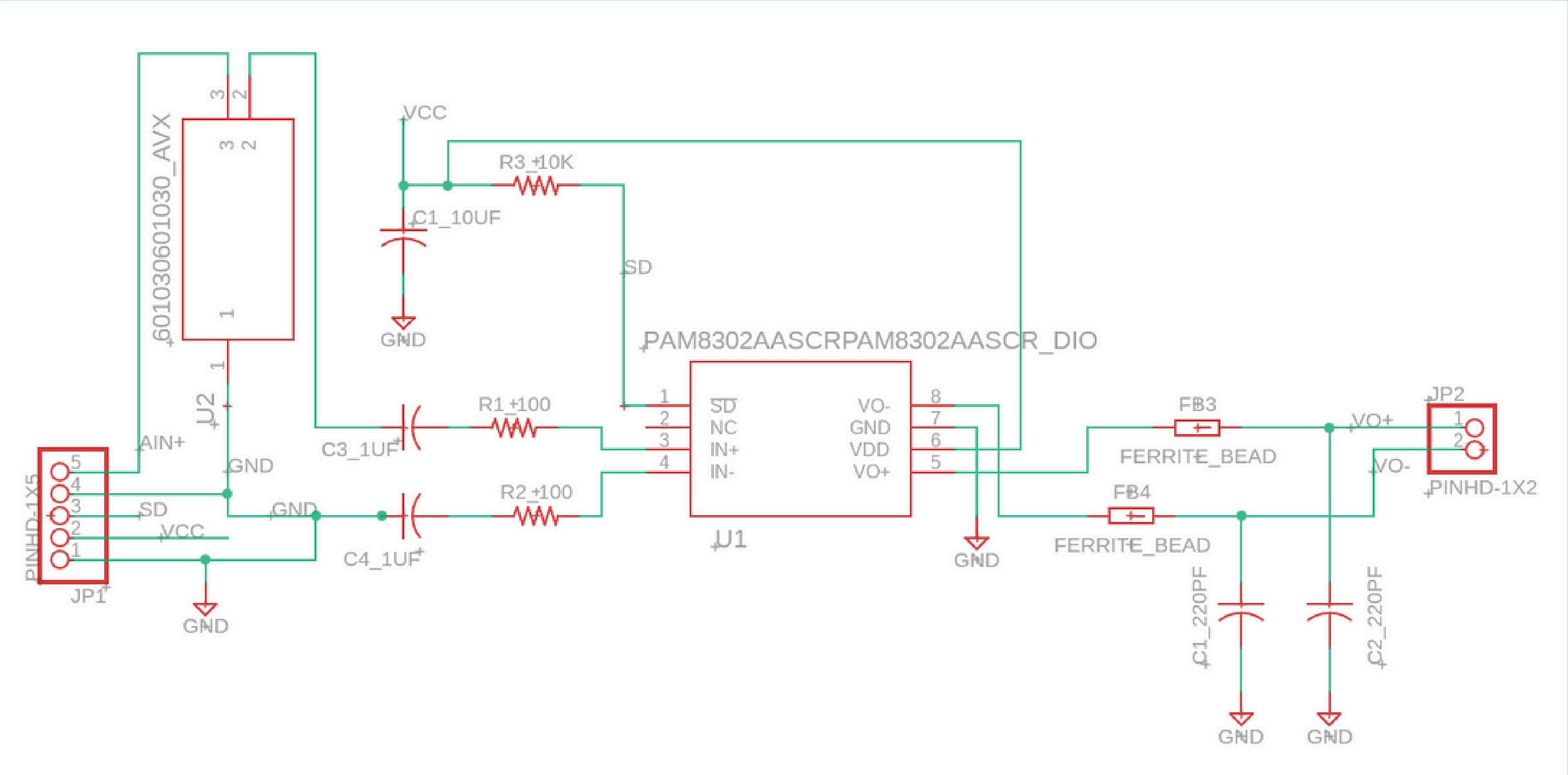

C1_0.1UF
C2_10UF
ESP32-S3-WROOM-1-N8ESP32-S3-WROOM-1_EXP
C3_10UF
SW1
SW2

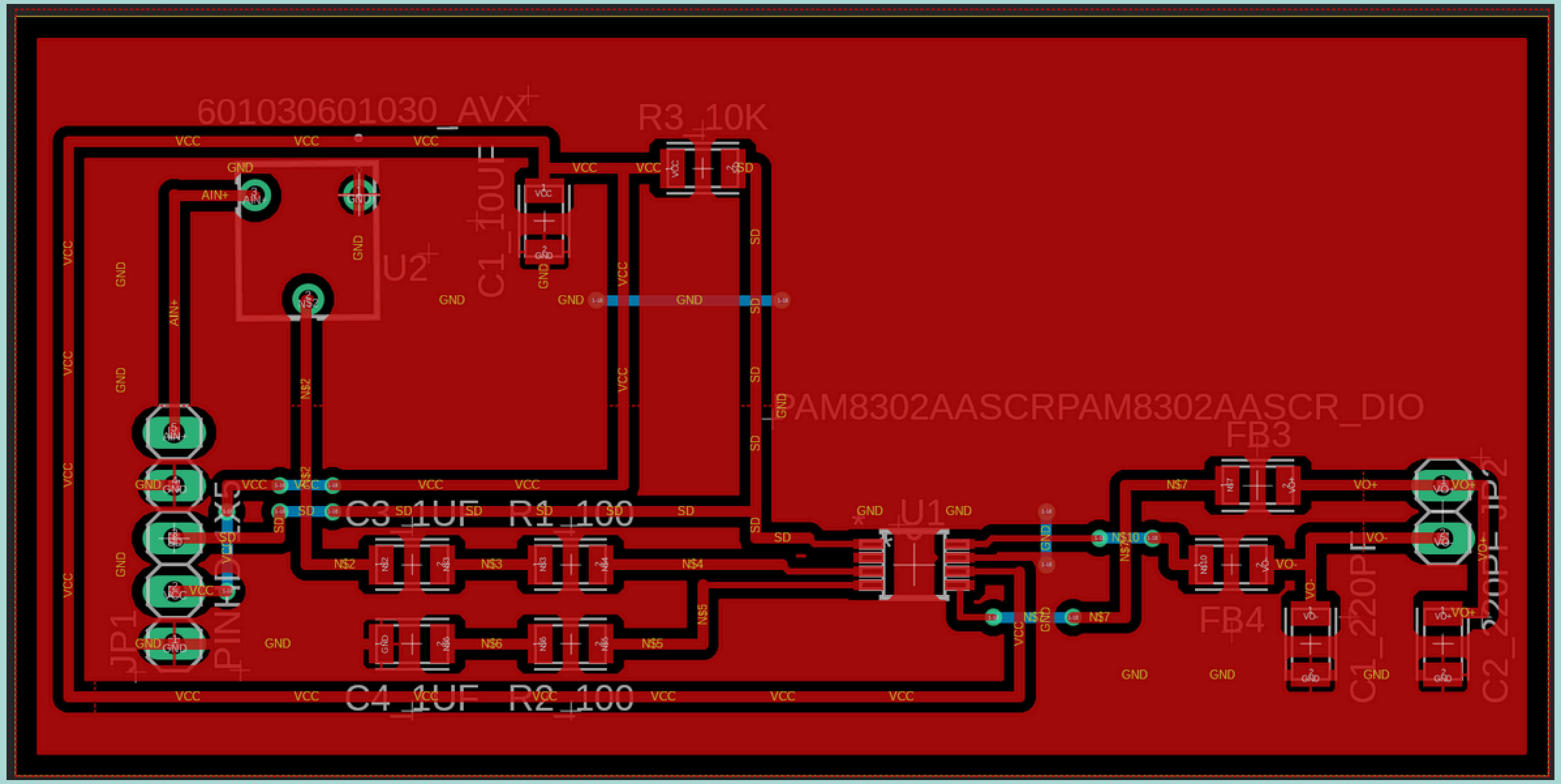
Vibration Driver



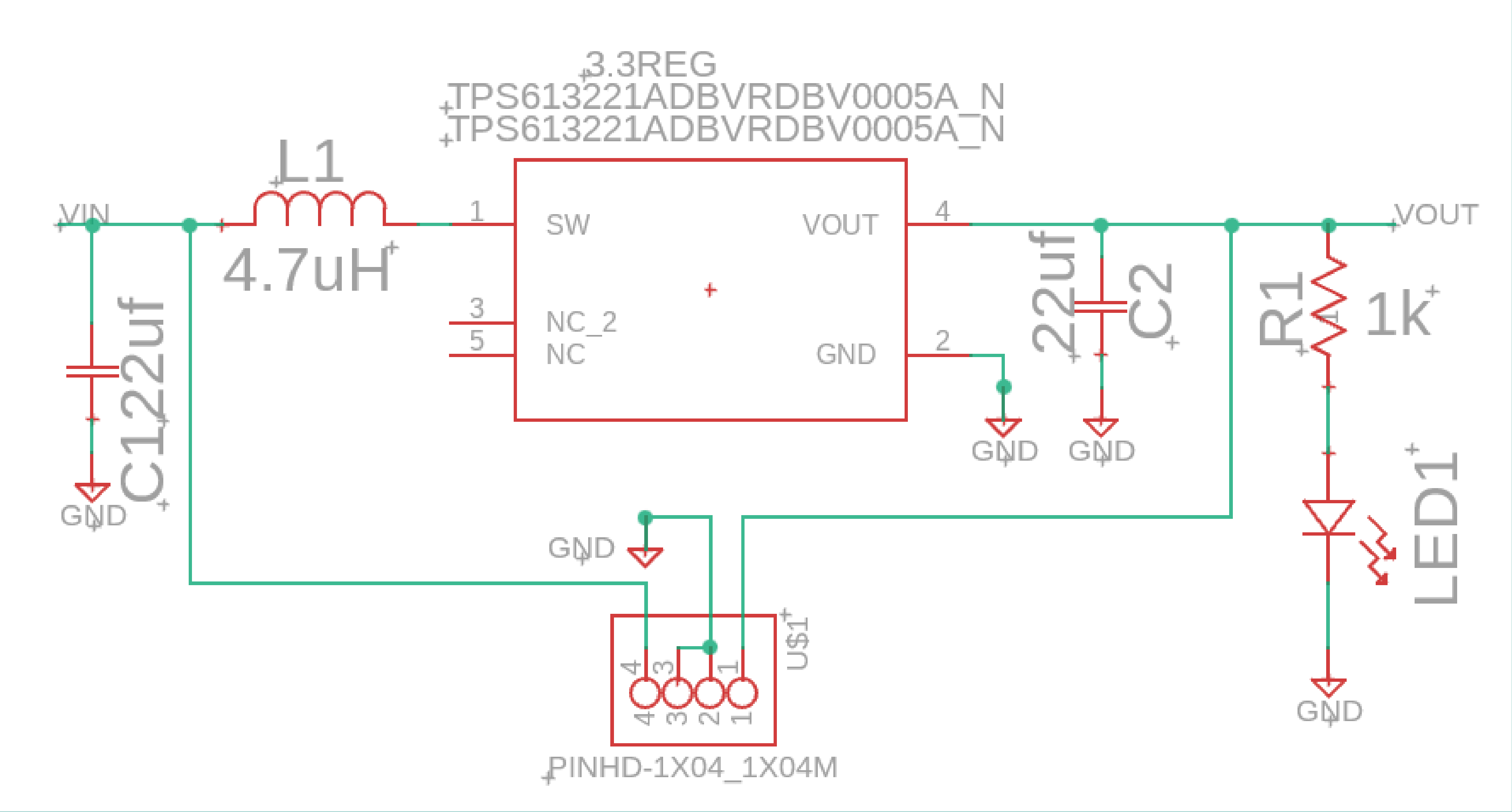


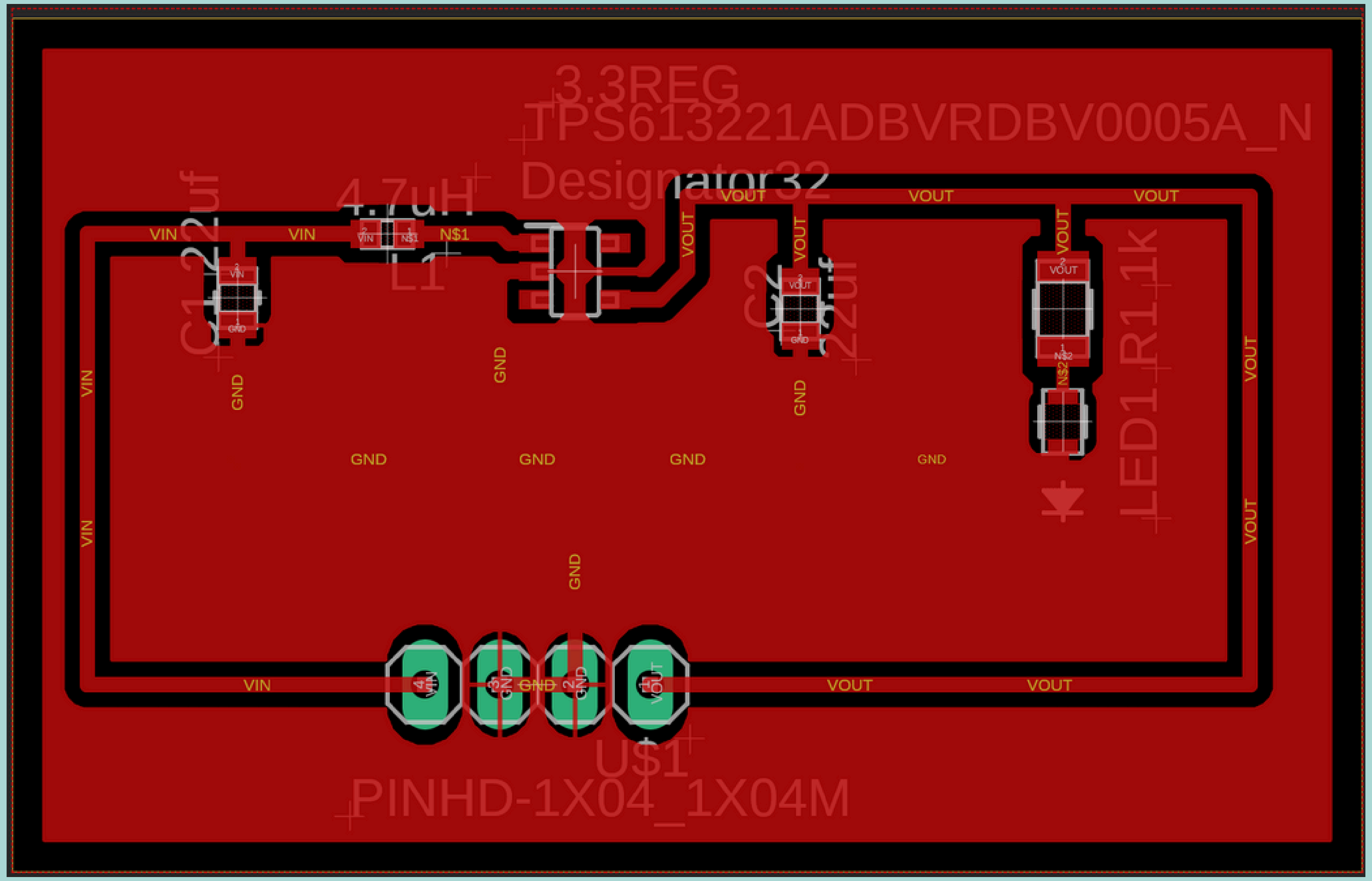
Audio Amplifier



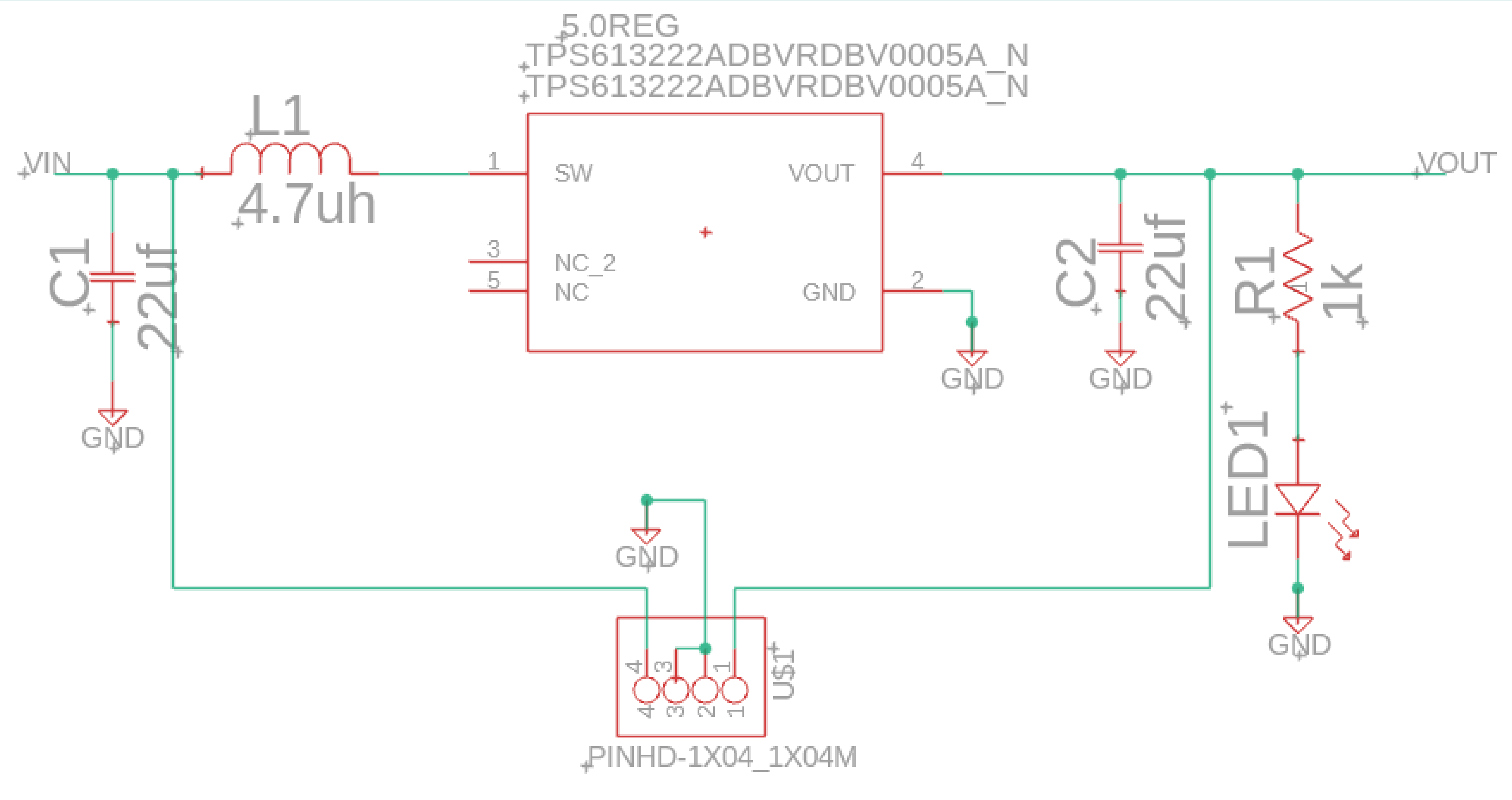


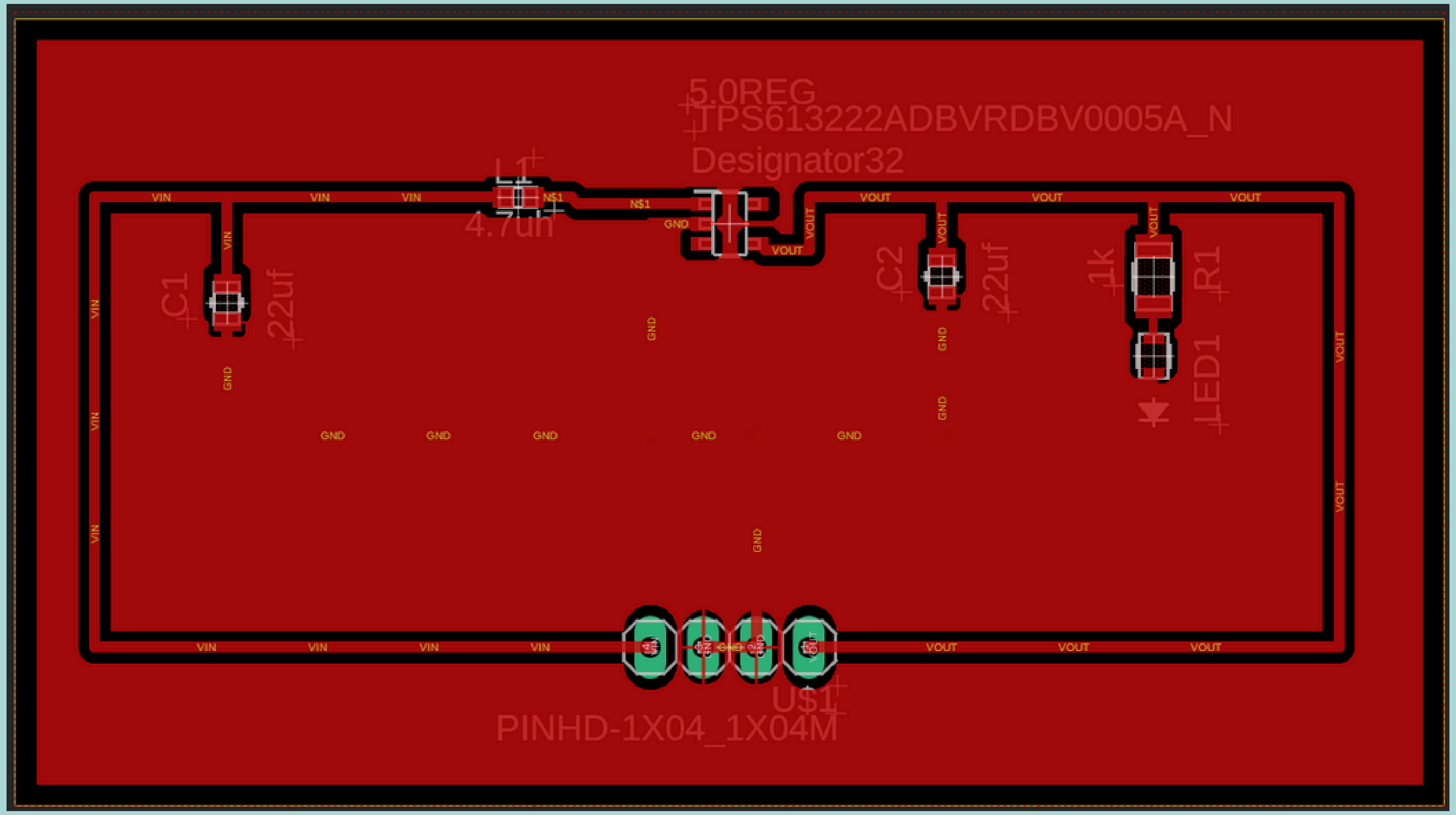
3.3V Regulator





5V Regulator





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 Initialization

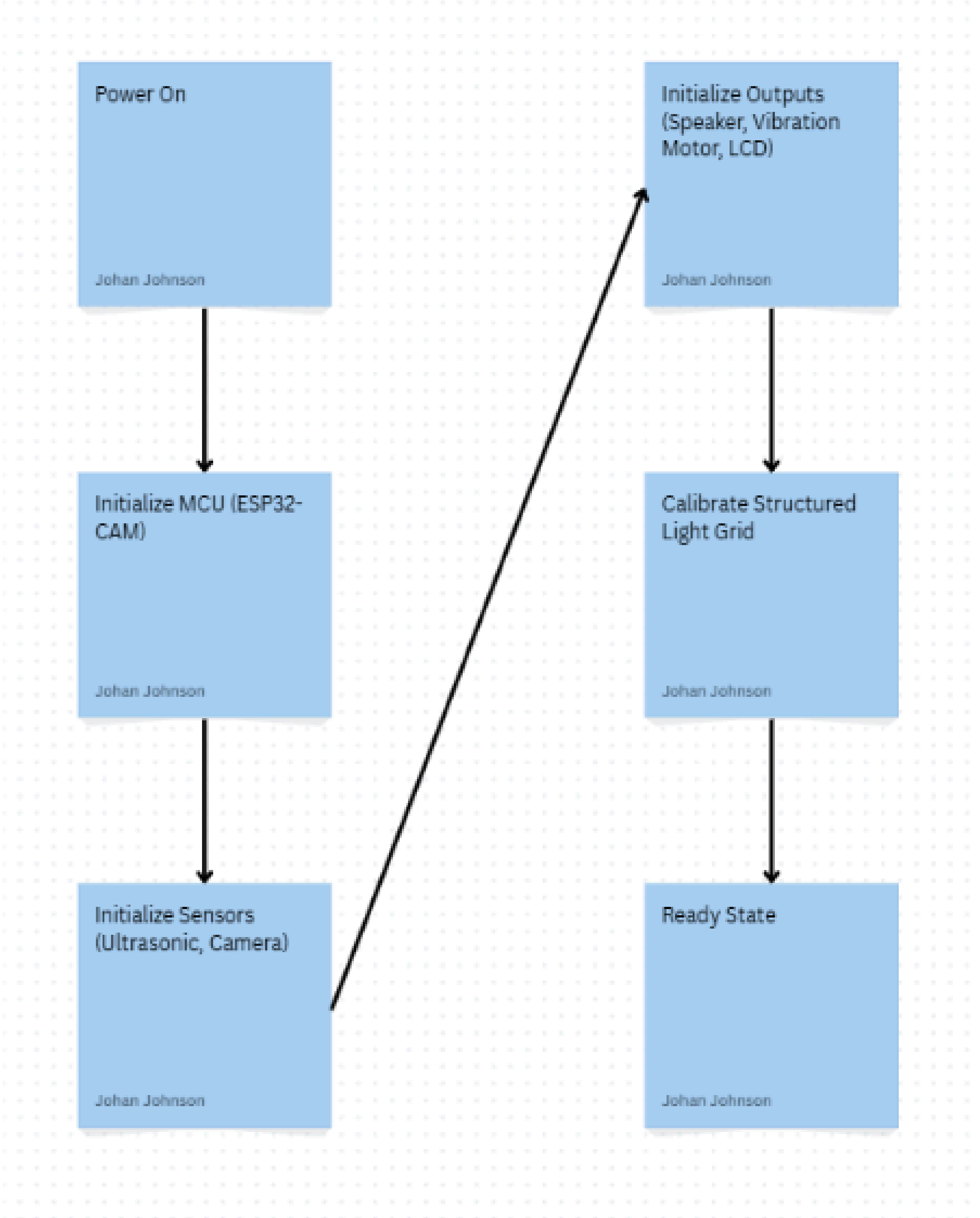


Figure 40: System Startup and Initialization Flowchart

Obstacle Algorithm

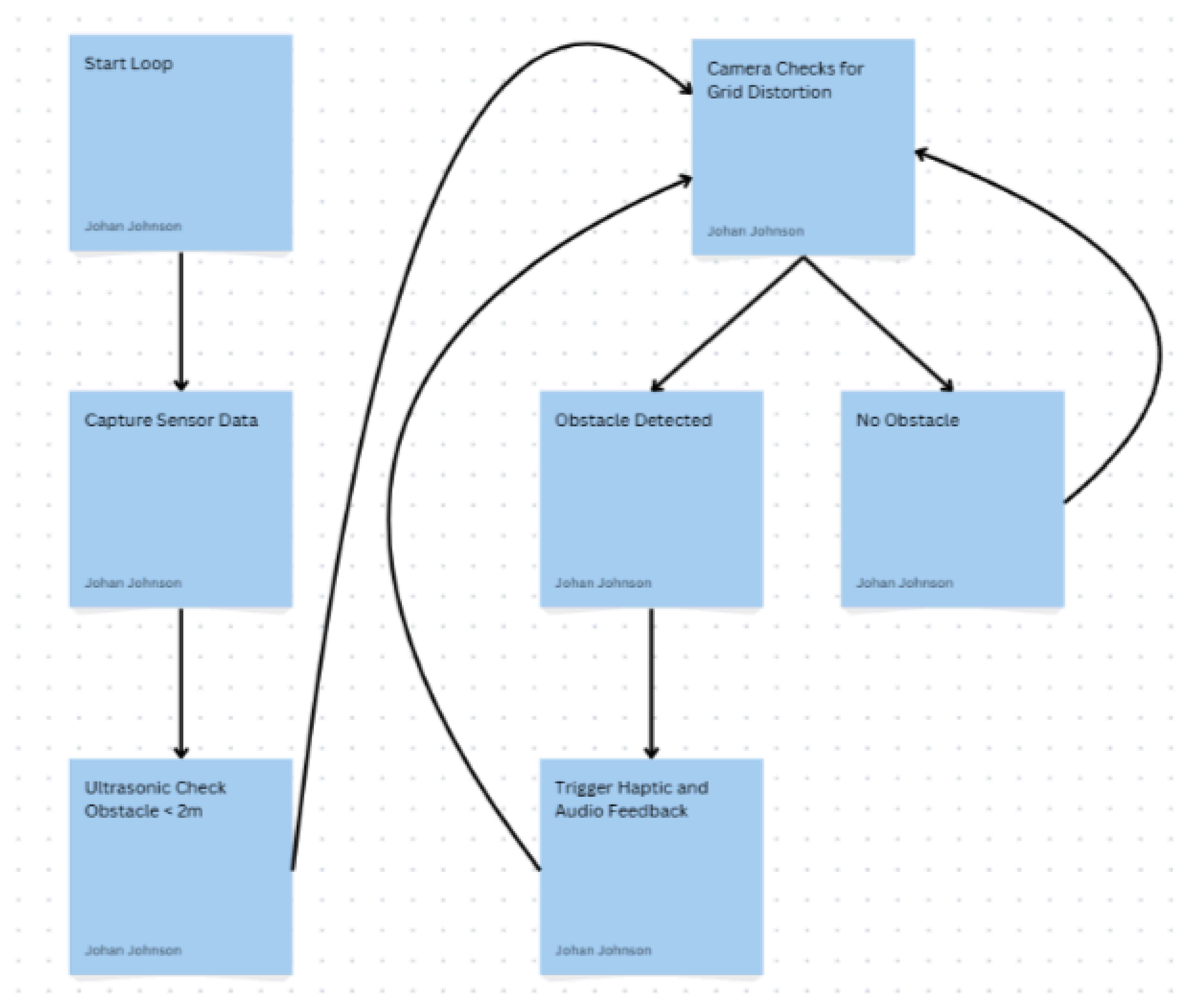
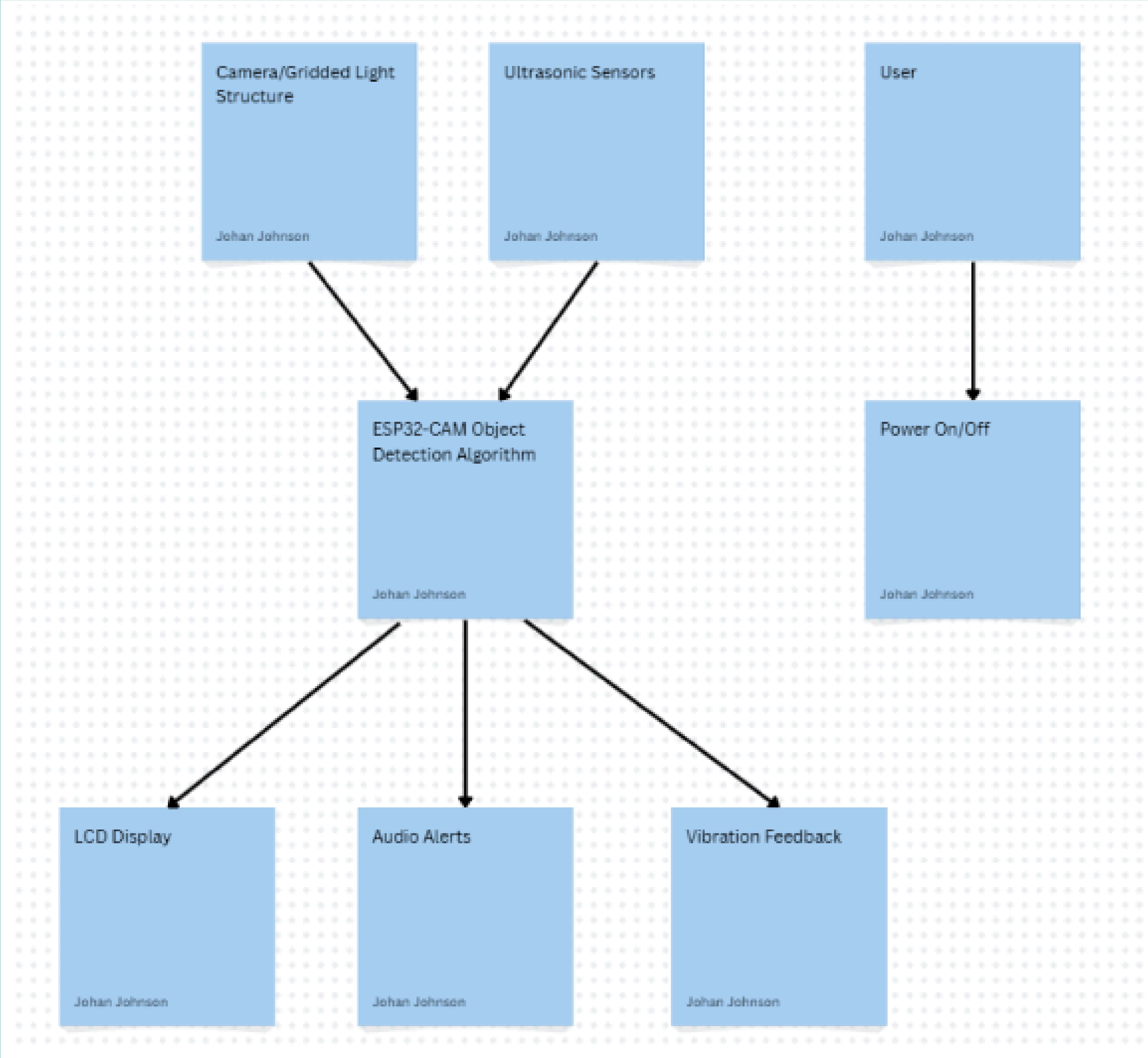
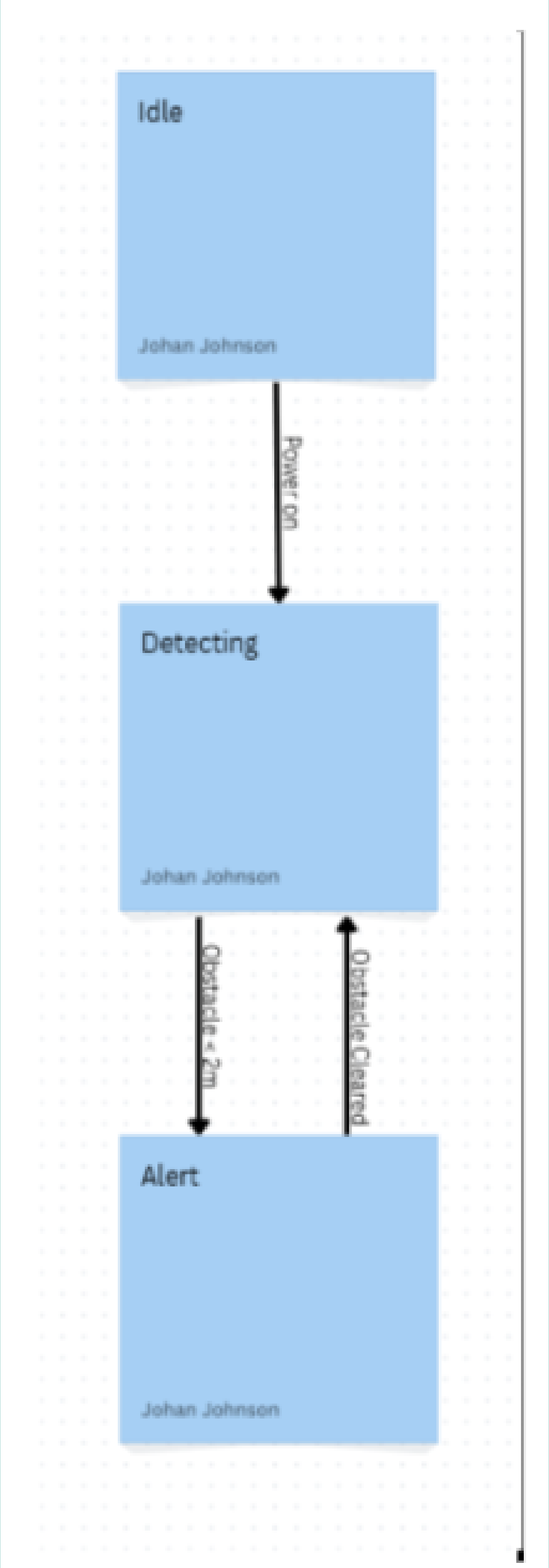


Figure 41: Obstacle Detection and Feedback Flowchart

System Input and Output



State Diagram



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 $pitch$).

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

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

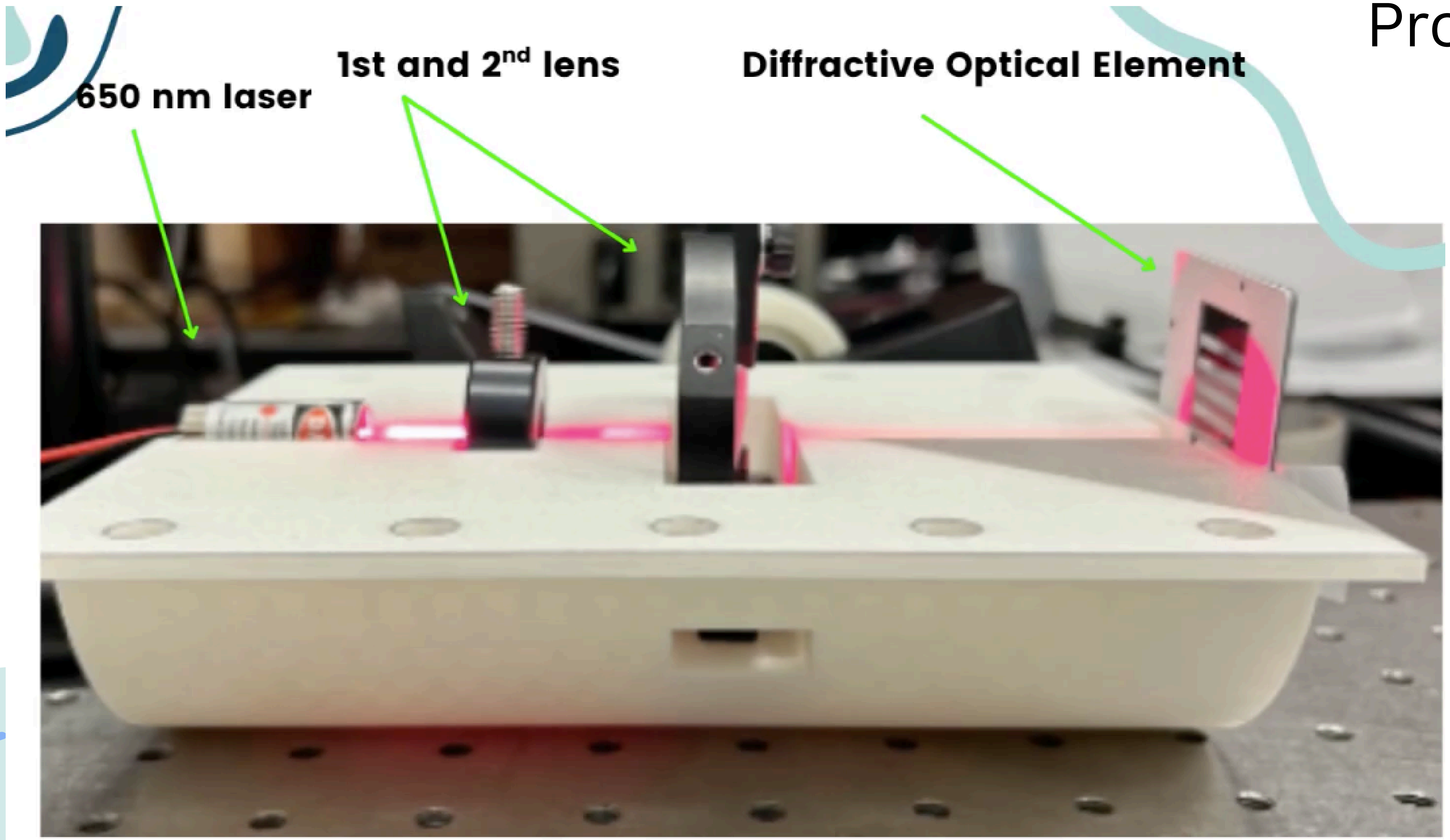
$$diagonal\ \sqrt{3.52^2 + 2.64^2} = 4.41mm$$

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

Horizontal scene width:

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

HARDWARE TESTING OF OPTICAL DESIGN COMPONENTS



Projected pattern at 2 meters with 650nm band pass filter

HARDWARE TESTING OF HARDWARE DESIGN COMPONENTS

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

SOFTWARE TESTING

Verified specs: 2m detection, <250ms latency
Unit + integration tests on sensors & feedback
Field trials: 98% obstacle detection success
Feedback triggered within 200ms
Next Steps: expand dataset & outdoor stress tests

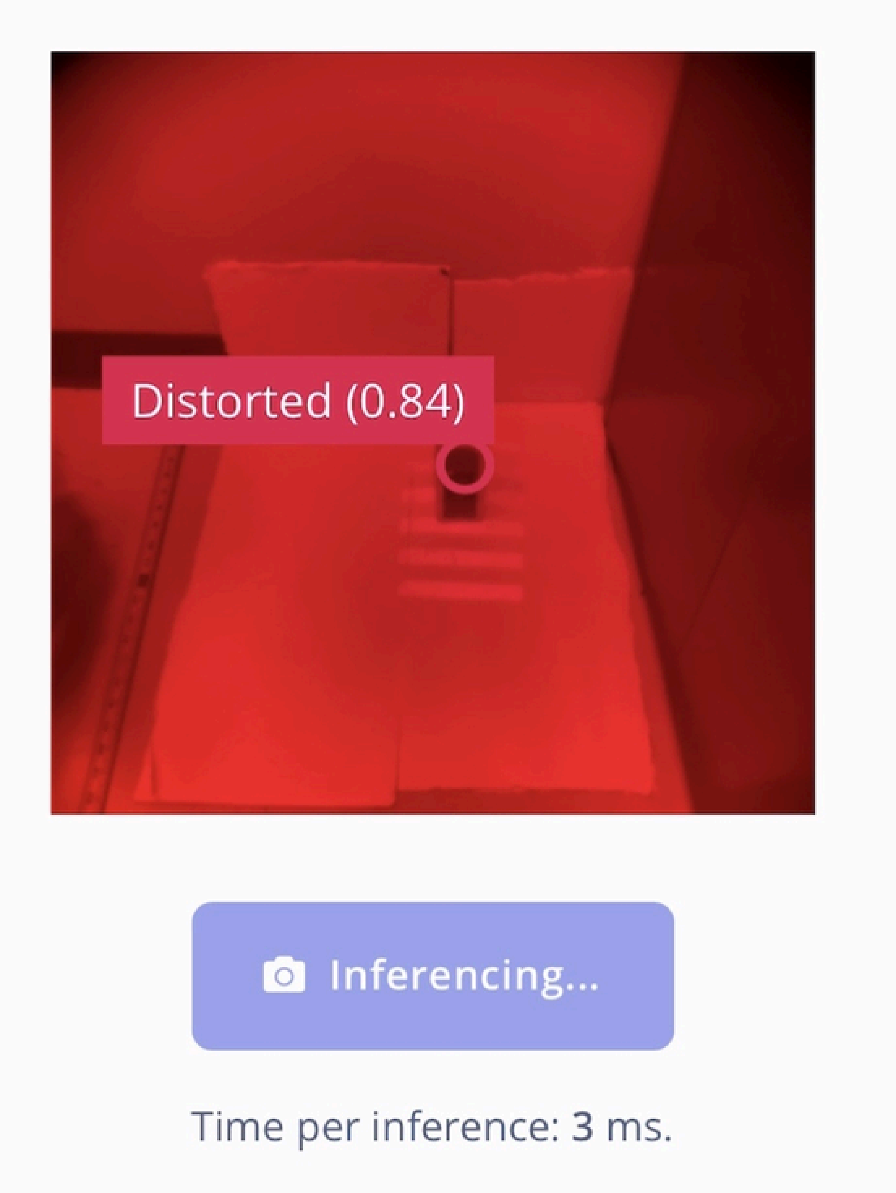
PERFORMANCE EVALUATION

Metric	Test Method	Tool/Equipment	Pass Criteria
Obstacle Detection Range	Place object at increasing distances and record detection distance	Laser rangefinder, ruler, ultrasonic sensor distance	Must detect obstacles at 2.0+0.2 meters
Accuracy	When testing outdoor/indoors place multiple objects at random distances/angles	Multiple object types (tree, door, person, wall)	98% detection of objects within range
Battery Life	Fully charge system and run in idle/active conditions for extended duration	Stopwatch	Last at least 6 hours under active usage
Response Time	Measure time from obstacle appearance to actuator output	ESP32-CAM	Signal sent to actuator $\leq$150ms after detection
Sensor Field of View	Rotate obstacle around sensor	Rotating test platform	Detects object within 60° horizontal field
Light Compatibility	Test detection in full daylight and dim room conditions	Outdoor test during the day, and indoor settings.	Detection is consistent in both lighting cases.

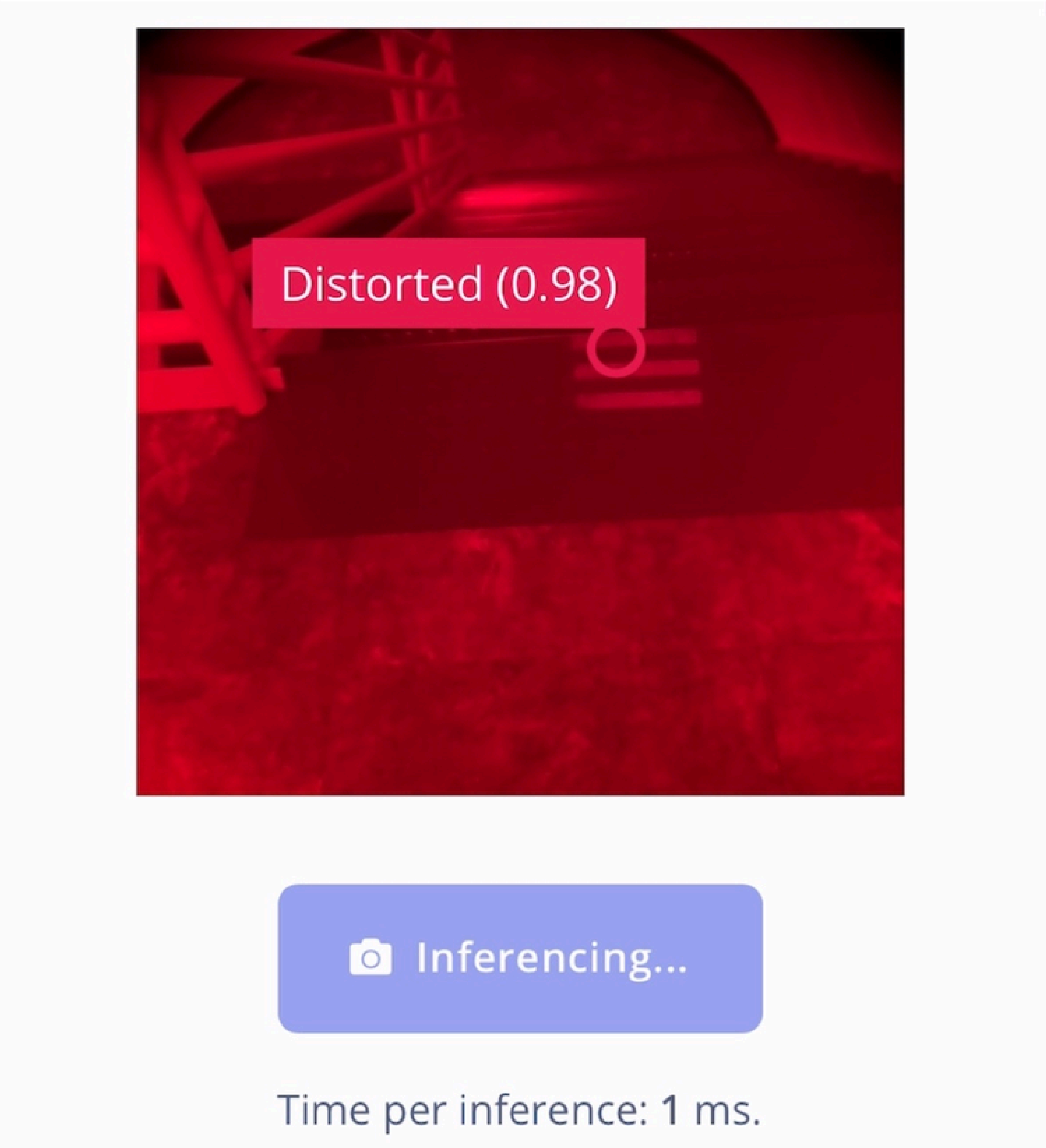
PERFORMANCE EVALUATION

Succesful Trials

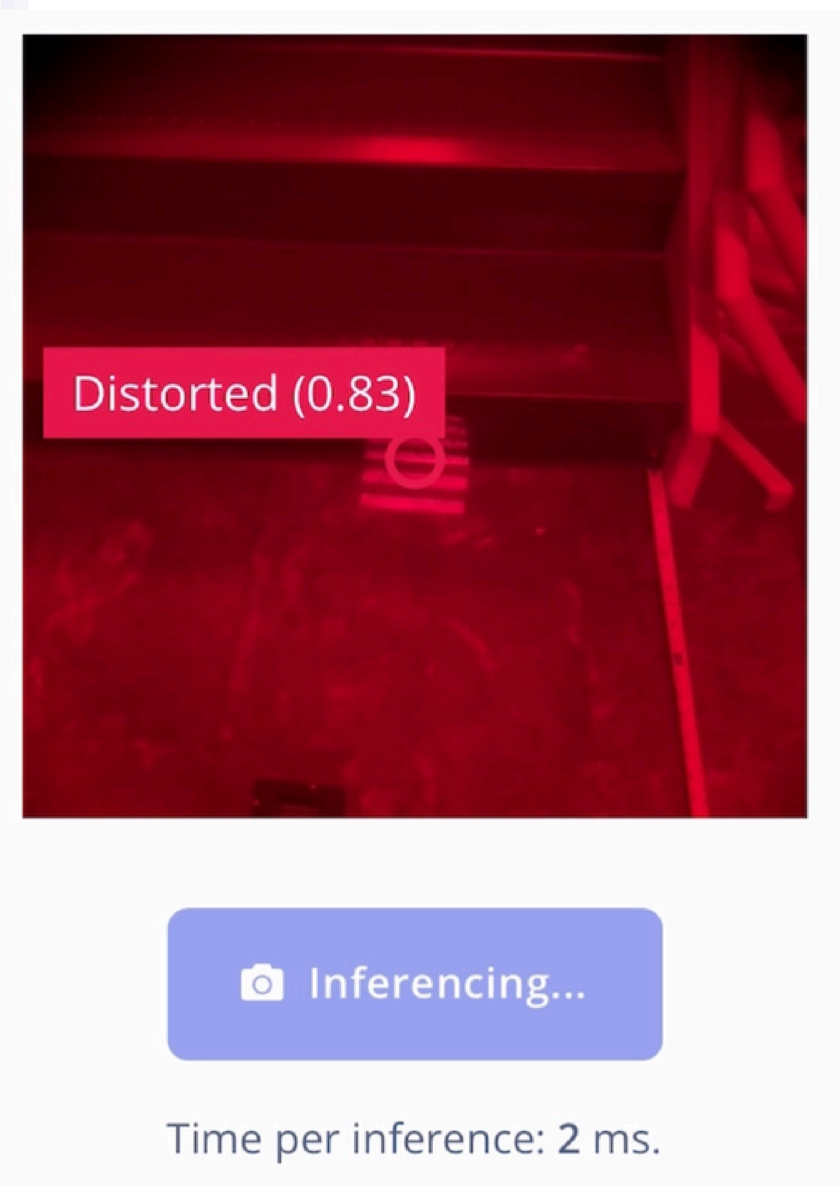
The bottle and “0.84” shows object detection at 2 m



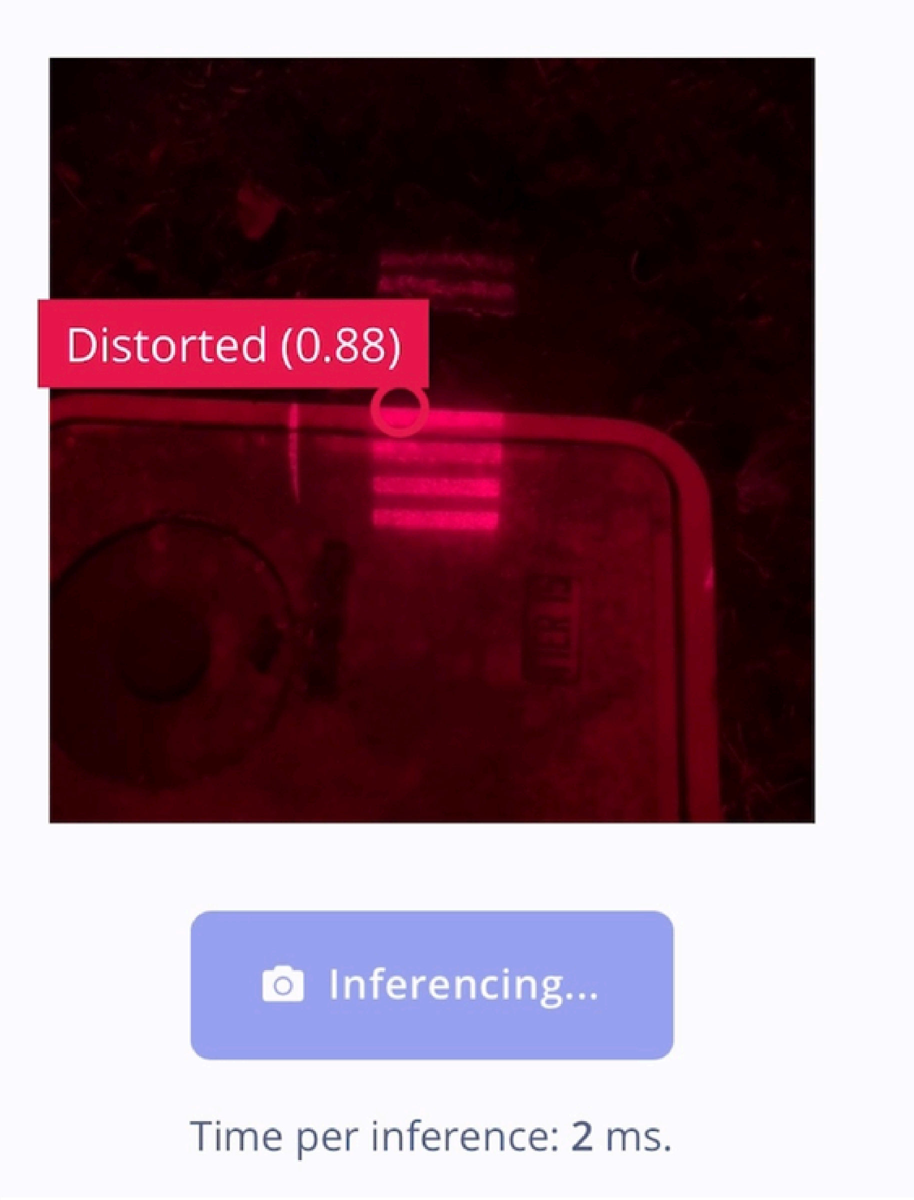
Detection of drop off from stairs



Detection of steps up



Detection of outside “ditch”



CHALLENGES AND PROPOSED SOLUTIONS

Challenges

The machine learning algorithm needs to be able to give directional outputs.

The projected pattern is barely visible by camera unit in bright daylight.

Proposed Solutions

More training on the model as well as adding code that accounts for the baseline between the camera and laser to create a depth map.

Increase output power from laser from 50mw to 200-250mw output laser.

OVERALL INTEGRATION

Subsystem	Description	Purpose in System
Obstacle detection and feedback module	This system will include ultrasonic sensors, a microcontroller with camera, vibration and speaker.	This will help detect obstacles in real-time and alerts the user through haptic and audio feedback.
Power supply and battery management	Provides regulated voltage and power to all system components for extended periods.	Ensures consistent and reliable operation of the system over 6-10 hours of usage.
User interface and display	LCD and LED indicators used for real time debugging and feedback during testing phases.	Assists in development and debugging during SD2.
Housing and enclosure	Encloses and mounts all hardware components on and around the shoe without messing with user movement.	Protects the hardware, ensures safety, and maintains comfort for visually impaired users.

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
- Verify hardware interfaces
- Develop bench tests for subsystems

- Finalize and review 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

- Develop and maintain ESP32-CAM code for system control
- Work with EE team to debug and ensure proper hardware software integration
- Support integration of the optics subsystem with the firmware.
- Help test and troubleshoot the full system prototype

Next Steps:

- Program PCB
- Test PCB power regulation, sensor connections, and motor driver outputs
- Assemble and integrate hardware subsystems for prototype validation
- Develop and debug ESP32 firmware for sensor data and motor control
- Align and calibrate optical subsystem, documenting performance results

Thank you!

PRESENTED BY GROUP 5