N.A.V.I.S. NAVIGATIONAL ASSISTANCE FOR VISUALLY IMPAIRED SHOPPERS

Critical Design Review

Spring 2025 / Summer 2025 – Group 10

Meet the team

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Motivation and Background

- According to the WHO, over **2.2 billion people** worldwide are affected by visual impairment.
  - *Some conditions are **uncorrectable** by glasses, medicine, or surgery, often caused by **age-related disorders** (e.g., macular degeneration, glaucoma).*
  - *These are classified as **'low vision'** by the NIH.*
- The CDC predicts that, in the U.S., **low vision among adults 40+ is expected to double by 2050**.
- This project focuses on individuals with **visual acuity from 6/18 to 3/60**, who may struggle with recognizing objects beyond **arm's length.**
- Daily activities often require **caregiver assistance**, which can reduce **independence and quality of life.**
- Our goal: develop a **portable assistive device** to help users **navigate grocery stores**, **locate items** (within 0.5m), and **avoid obstacles.**

Goals and Objectives

Navigation & Guidance:

- Create a system for users to input their shopping list.
- Plan an efficient path through the store to reach all requested items.
- Guide users to specified items within 0.5m accuracy through both haptic and audio cues.
- Account for restroom breaks, navigation to checkout, and requesting assistance.

Obstacle Detection & Avoidance:

- Track cart speed and position through the store.
- Warn users through audio and haptic cues of obstacles detected by IR emitter and cameras.
- Process and deliver cues fast enough to allow user to react.

Physical Device:

- Lightweight and portable with simple cable management.
- Quick and easy to mount and remove. Compatible with most shopping carts.
- Modular speaker and haptic motor attachments to handlebar. Cues perceptible in noisy environments.
- Minimum 1 hour of operating time.

Engineering Requirements and Specifications

Specification	Target Value
Distance User Guided from Product	**Within 0.5 meter**
Success Rate	**At least 90%**
Collision Avoidance Latency	**<300 ms**
Size	Approx. 50x50x30 cm^3
Weight	2.5 - 5 lbs
Battery Life	At least 1 hour
Setup/Teardown Time	Within 5 minutes

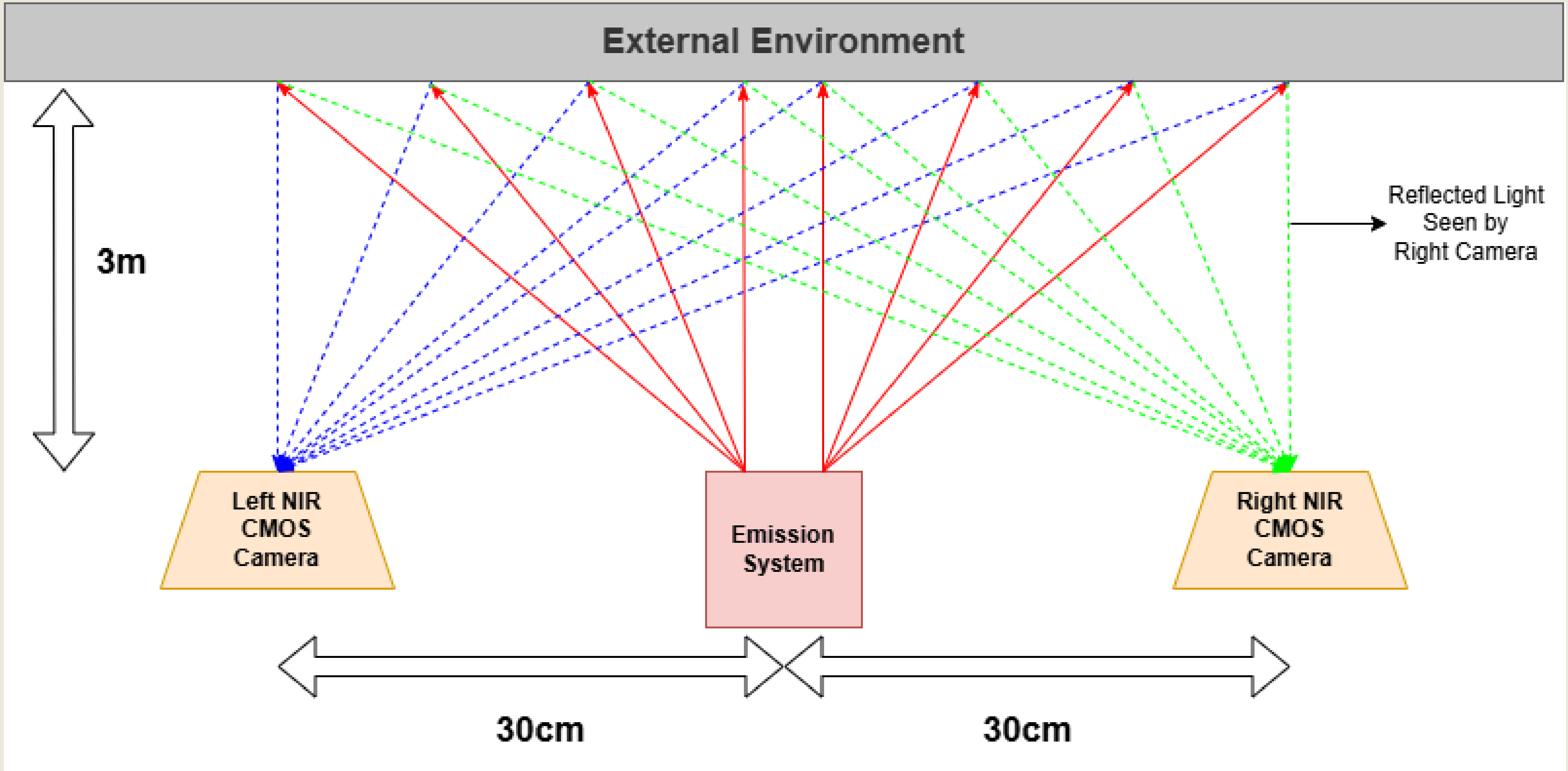
Component	Parameter	Target Value & Unit(s)
App Display Screen	Output Quality	480 pixels – 720 pixels
IR Camera Sensor	Range	1 - 6 meters
IR Cameras	Field of View	At least 100°
IR Emitter	Field of View	At least 100°
Haptic Motors	Signal Discretion	3+ distinct vibration patterns
Speaker	Output Volume	At least 60dB SPL at 0.5m

Optical Design Specifications

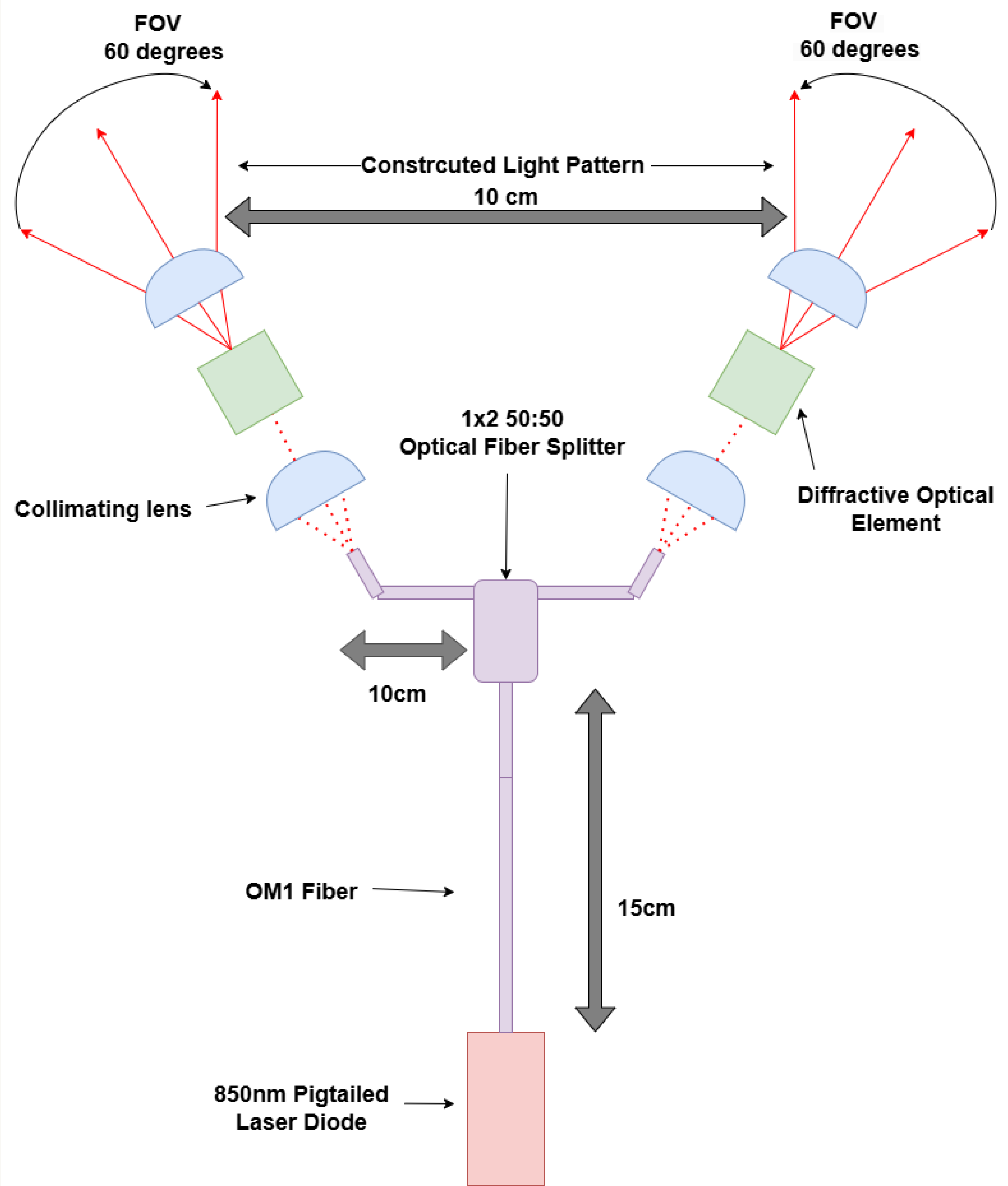
Component	Parameter	Target Value	Unit
Pigtailed Laser Diode	Optical Power	140	mW
	Wavelength	850	nm
	Operating Current	286	mA
	Operating Voltage	2.4	V
	Fiber Type	Multimode	
Fiber Splitter	Splitting Ratio	50:50	
	Port Configuration	1x2 or 2x2	
	Fiber Mode Type	Multimode	
	Operating Wavelength	850	nm
	Excess Loss	0.35	dB
	Splitting Ratio Accuracy	~±7	%
Collimating Lens	Focal Length	5	mm
	Diameter	3	mm
	Coating	AR	
DOE (Diffractive Optical Element)	FOV (V x H)	>40 x 40	Degrees
	Diffraction Pattern	Grid (50x50)	
Camera Sensor Module	QE (at 850nm)	50	dB
	SNR	20	dB
	Resolution	1920 x 1080	
	Dynamic Range	70	dB
	FOV (V x H)	>50 x 50	Degrees

HARDWARE DESIGN

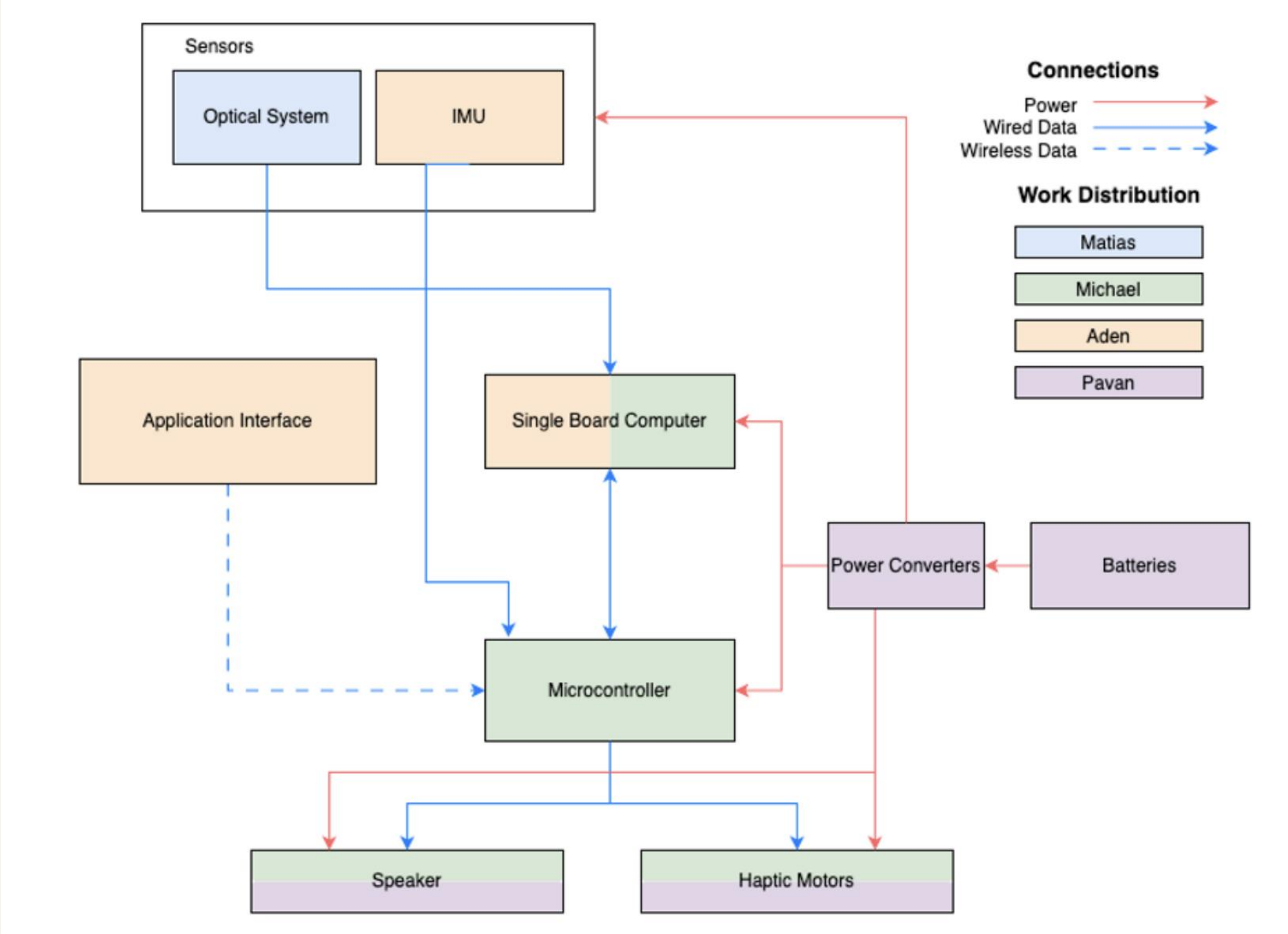
Optical Detection Hardware Block Diagram

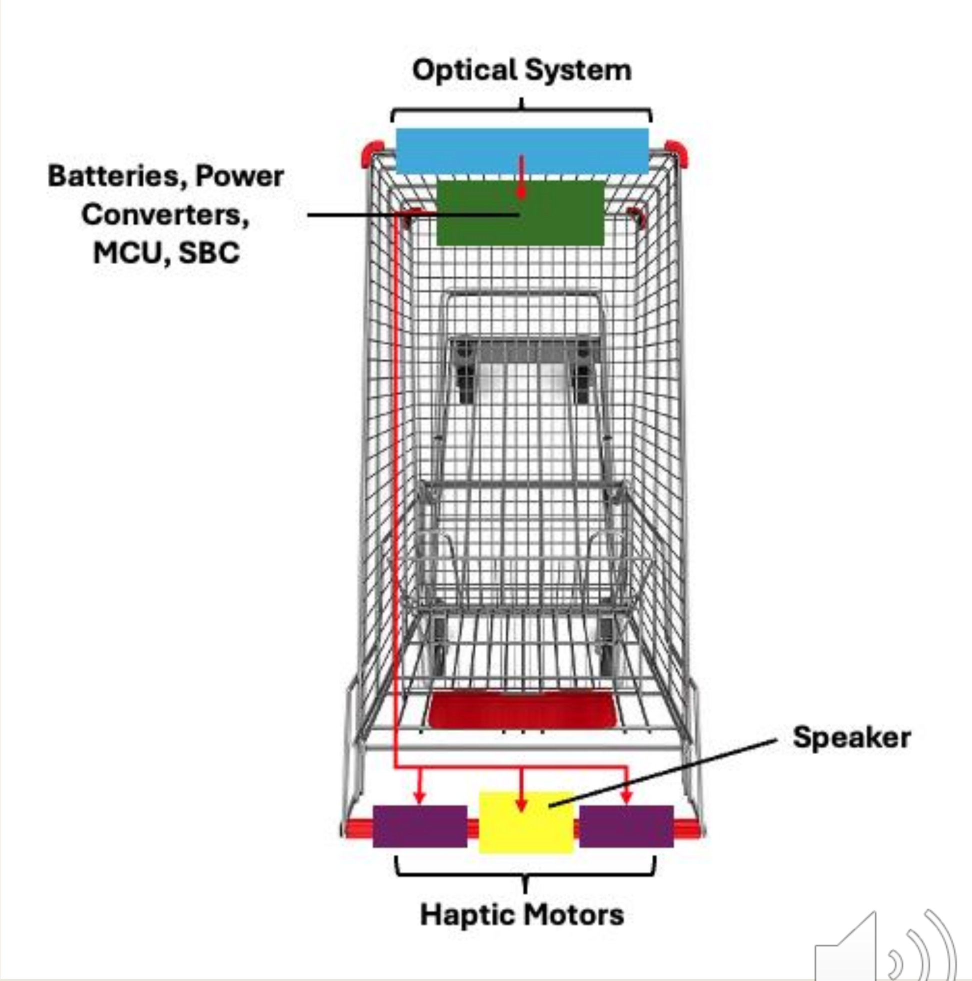


Optical Emission Hardware Block Diagram



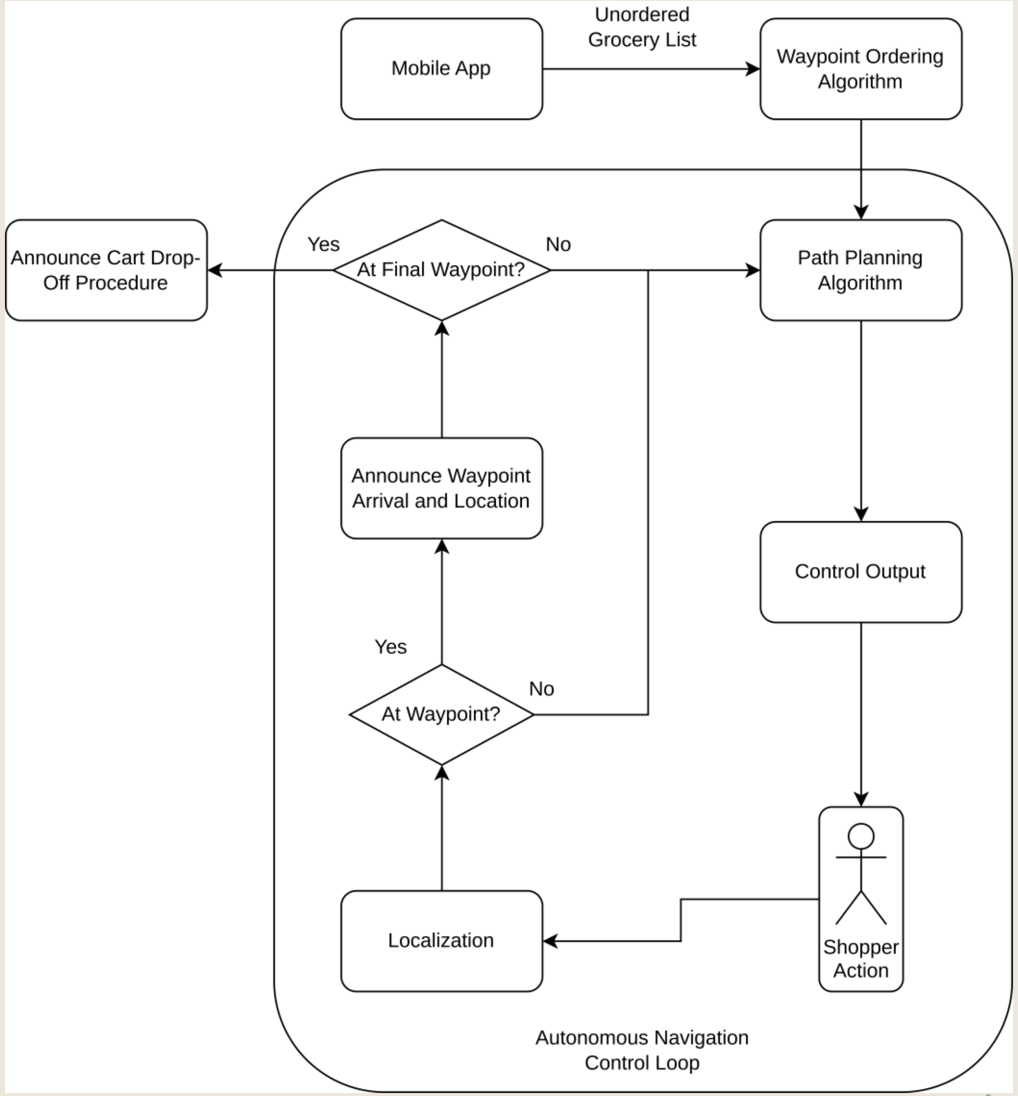
Electrical Hardware Block Diagram



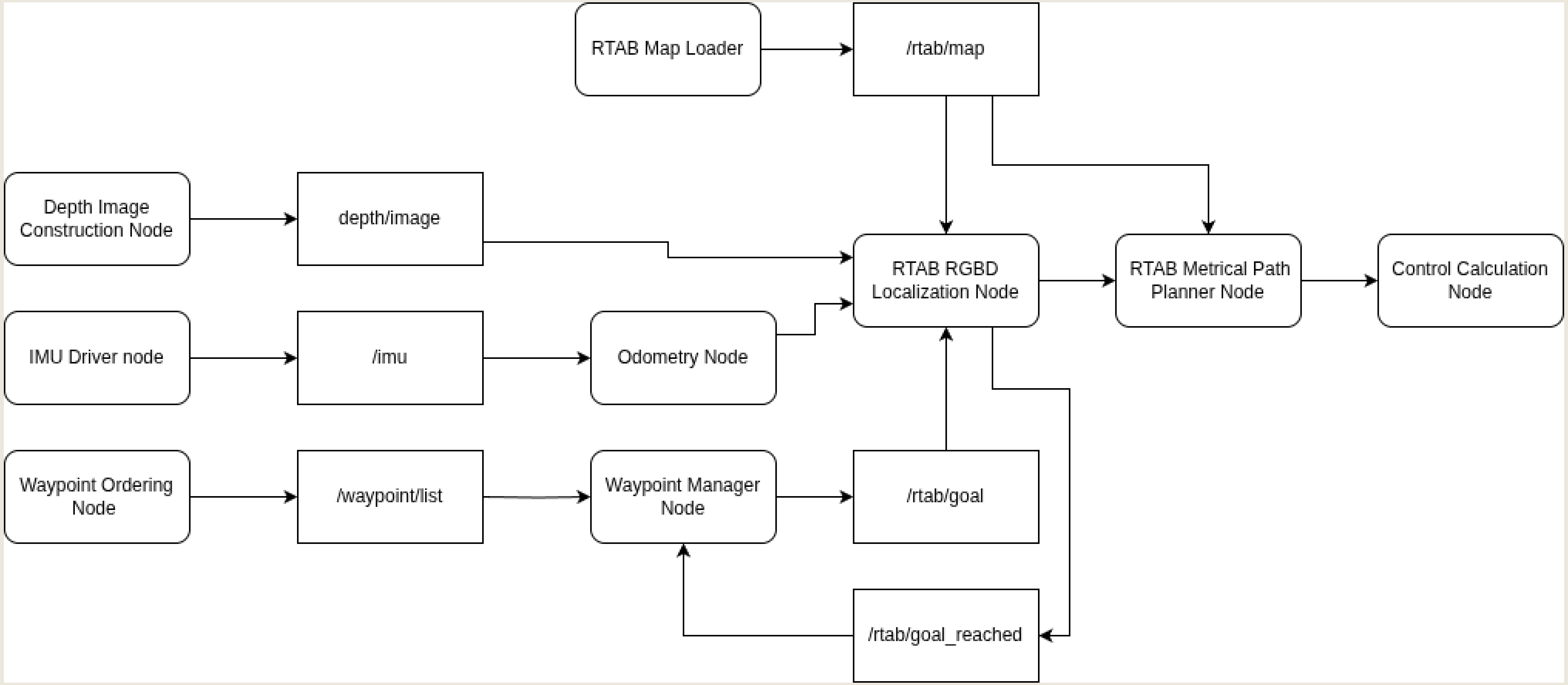


SOFTWARE DESIGN

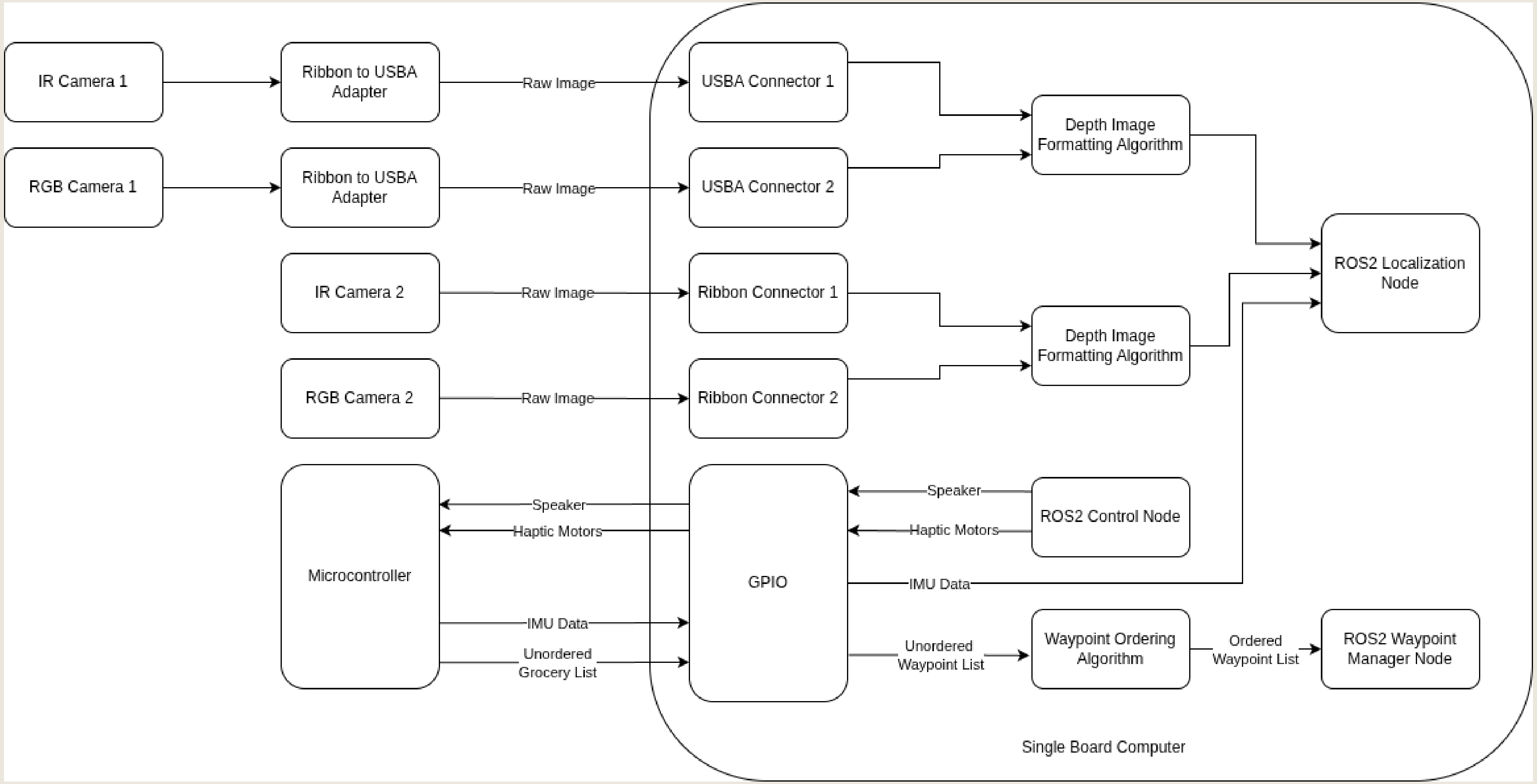
Autonomous Navigation Flowchart



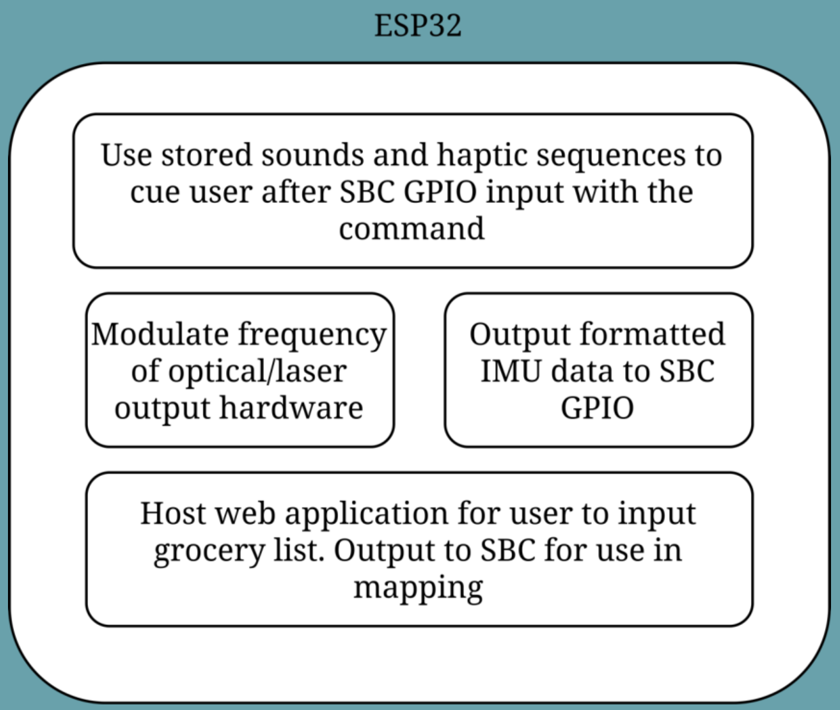
ROS2 System Architecture

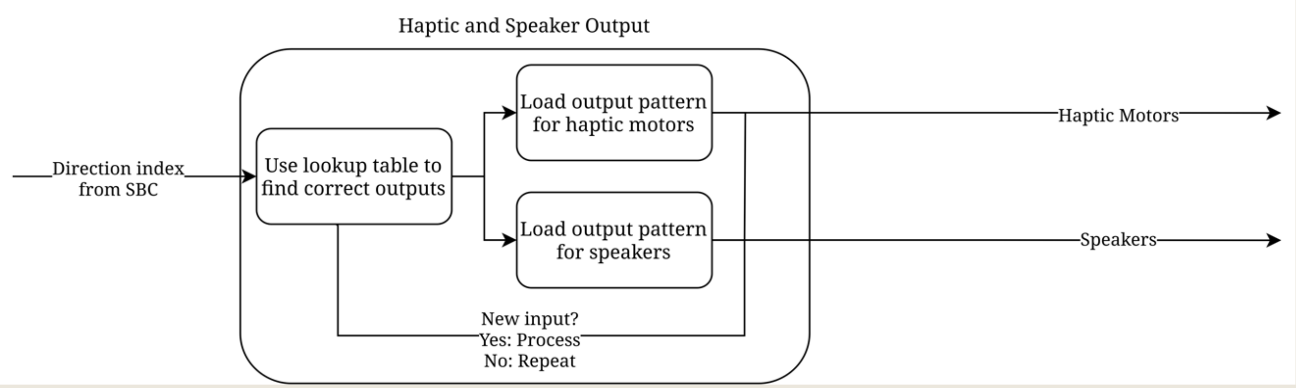


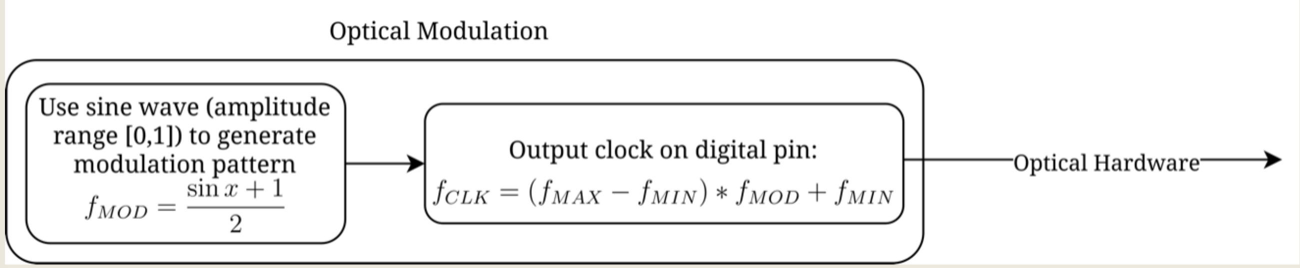
SBC IO Block Diagram



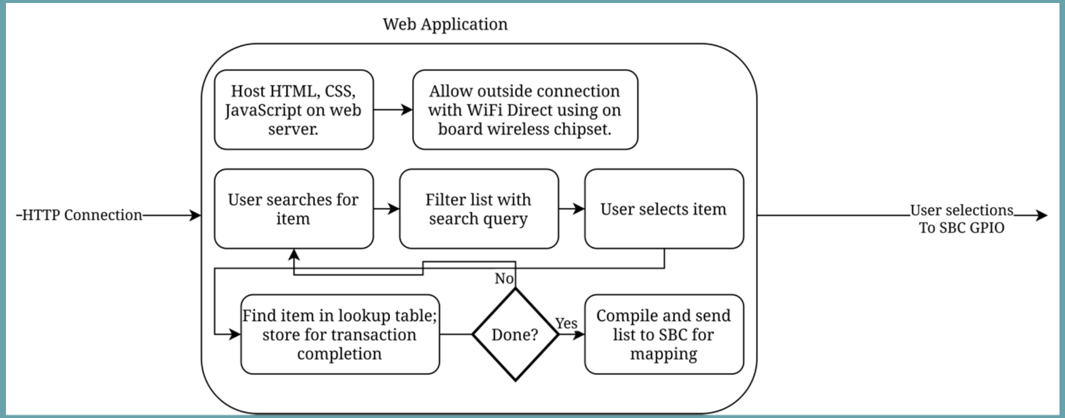
Microcontroller Programs

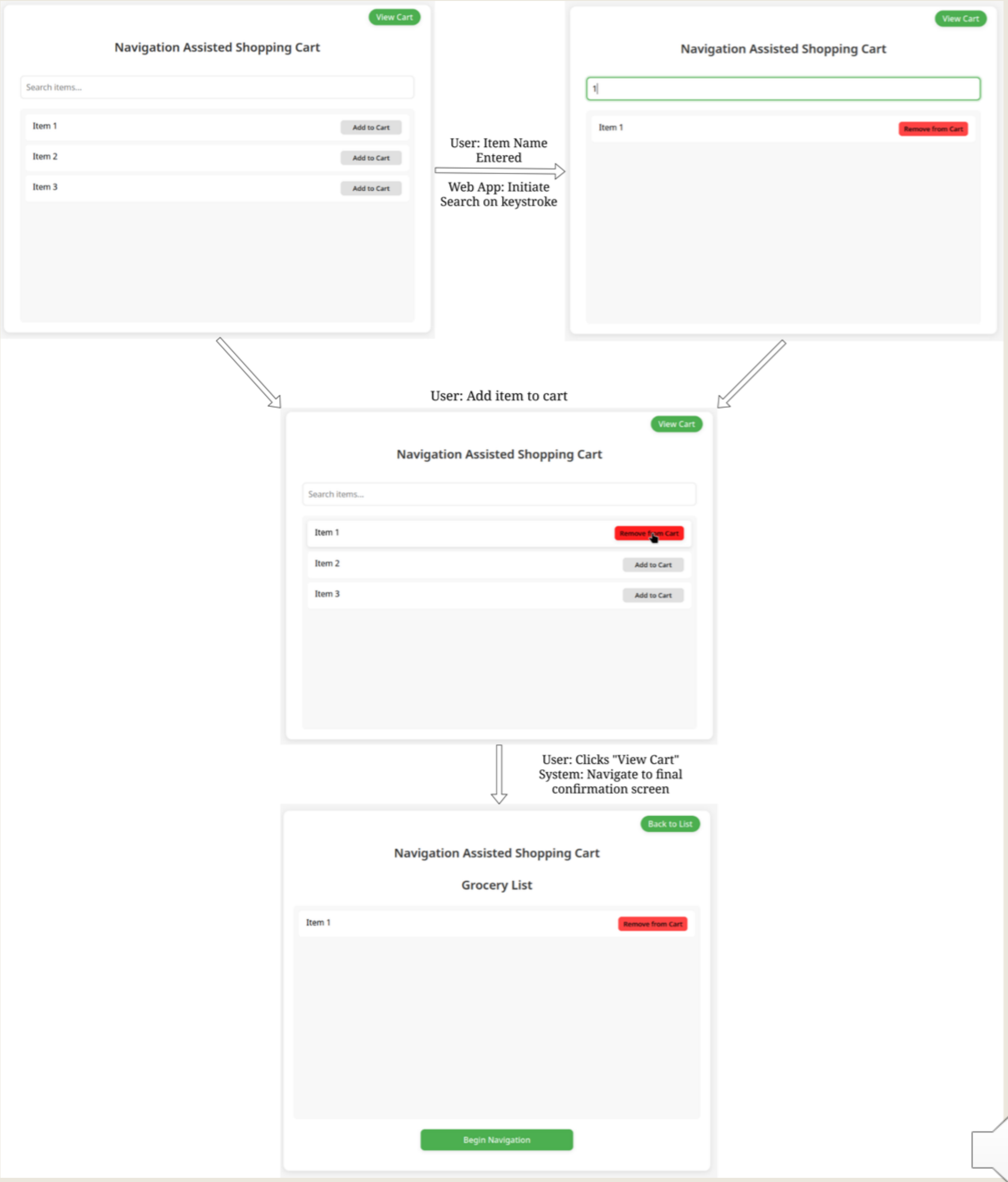






Microcontroller Programs – Web App Overview & UI





OPTICAL HARDWARE AND COMPONENT SELECTION

Depth Measuring System Technology

Technology	Depth Accuracy / resolution	Environmental constrains	Reliability	Feasibility	Cost
Active Stereo Vision	Medium-High – depends on light projection / camera quality and baseline	Low-Medium – sensitive to ambient NIR sources, occlusion and material reflectivity	High – struggles with low pattern density, no need for intense computing	Medium – relies on light projection, requires less computation	Medium-High
Passive Stereo Vision	Medium – depends on camera, baseline, disparity errors	Medium – sensitive to ambient lighting, reflections and occlusion	Medium – struggles with texture-ess object, and relies on intensive computation	Medium – relies on intensive computation to find features on objects	Low
Structured light depth sensing	Medium-High - depends on light projection / camera quality and baseline	Medium – Sensitive to ambient NIR sources and material reflectivity	Medium – relies on a single point of view, and projector quality	Medium – requires higher light projection quality	Medium
Sonar	Low-Medium – depends on pulse duration, sampling rate and speed of sounds variations	High – sensitive to non-solid objects	Low – unreliable for not solid objects	High – simple hardware and computation	Low
Lidar	Very High – dependent on accurate time of flight measurements and pulse width	Low – sensitive to object reflectivity	High – reliable if component quality and sampling rate is high	Low – relies on complex materials and components	Very High

Pigtailed Laser Diode and Driver Product

Product Manufacturer and Number	Optical Power	Fiber type	Operating Voltage (V)	Operating Current (mA)	Threshold Current (mA)	Price (USD)
Shengshi S780	120mW	MM	2.4	220	50	65
Civilasers 850nm Pigtailed Laser(SM)	80mW	SM	2.4	240	55	169
Laser Tree LT-FCLD-M850100	100mW	MM	2.4	240	55	180
Shengshi PLD-F85	120mW	SM	2.42.3	300	18	78.66

Product	Mode	Input Supply (V)	Max Output Current (mA)	Price (USD)
LDD200P Series 200mA	Constant current	5 - 12	200	$105.00
Thorlabs LDC205C Benchtop LD Current Controller	Constant current, constant Power	120 (AC)	500	$1210.31
ATLS1A104D	Constant Current	3.3 - 5	1000	$69.00

DOE Light Pattern and Product

Pattern type	Depth Information Quality	Environmental Robustness	Processing Complexity
Random Dots	High; Unique local features, low ambiguity	Moderate; Innefective with non-solid objects, resilient against occlusion	High; Exhaustive feature matching required
Dot Array	Moderate-high; Suffers from pattern ambiguity, dependent on number of dots	Low-Moderate; Innefectiove with non-solid objects	Moderate; Geometric asumptions would help,
Horizontal and Vertical Lines	Moderate; Suffers from ambiguity, Dependent on number of lines	Moderate-High; Effective with non-solid objects	Low; edge detection is computationally efficient

Product Manufacturer and Part Number	Grid Size (V x H)	Field of View (V x H)	Material	Line Density in a 100cm^2 area 3m away Possible features	Cost
DigigramDTC-25	60 x 60	40 x 40	PET or PMMA	5.4 16.47	$80
Laserland QYG-004	51 x 51	30 x 30	PMMA	6.2 22.63	$1.5
HOLOEYE DE-R256	51 x 51	30 x 30	Polycarbonate (PC)	6.2 22.63	$72
Lasermate DOE-SG60	60 x 60	40 x 40	PET or PMMA	5.4 16.47	$100

NIR Sensor Technology and Product

Sensor Technology	Spectral Compatibility and Sensitivity	Image Quality	System Integration	Cost and Availability
CMOS	Moderate; QE of 50% at 850nm, higher in back-side illumination sensors	Good resolution; moderate noise; decent dynamic range	High; Low power and easy integration	Low cost High availability
sCMOS	High; QE of >60% at 850nm; good for low light	Exceptional resolution; Low noise; Wide dynamic range	Moderate; Higher power consumption, higher computational power	Moderate-High cost Moderate-High availability
CCD	Moderate; QE of 50% with back-side illumination	Low noise; Excellent uniformity; Slower readout	Moderate; Higher power consumtion, larger size, outdated	Moderate cost Moderate availability
EMCCD	Very High; QE of >90% at 850; good for low light	Ultra low noise; High uniformity; few photon detection	Very low; Complex electronics, cooling requirements	High cost Low-Moderate availability

Camera name (Sensor name)	QE at 850nm (%)	SNR (dB)	Resolution	Dynamic Range (dB)	Price (USD)
Arducam Pivariety 2.2MP Mira220	54	40	1600 x 1400 (2.2 MP)	62dB	110
Arducam 1MP OV9281	~30	38	1280 x 800 (1MP)	68	25
Thorlabs CS165MU	20	69	1440 x 1080 (1.6MP)	66.4	850
Arducam 2MP IMX462	90	42	1920 x 1080 (2MP)	72	40

Fiber Optic Splitter Technology & Product

Splitter technology	Insertion and Excess Loss (dB)	Wavelength Uniformity	Availability and Cost
FBT	Moderate; Insertion loss: 3.2-3.5 Excess loss: 0.19-0.99	Moderate; Sensitive to wavelength changes of more than 100nm	High availability Low cost
PLC	Low; Insertion loss: 3.11-3.21 Excess loss: 0.1-0.2	High; Sensitive to wavelength changes of more than 200nm	High availability Moderate cost

Product Distributor and Number	Insertion and Excess Loss (dB)	Splitting Ratio Accuracy	Operating Wavelength Range	Cost
Thorlabs #TG625R5F1A	Insertion: ≤4.2 dB, Excess: ≤0.6 dB	50:50 ±6.5%	850nm ±40nm, With the posibility of handling other wavelengths at higher attenuation	$249.90
eBay #315291630925	Insertion: ≤3.8 dB, Excess: ≤0.3 dB	50:50 ±6.5%	850nm ±40nm, With the posibility of handling other wavelengths at higher attenuation	$28.49
Go4Fiber # MST-1X2-85-50/50-R-3-1	Insertion: ≤3.9 dB, Excess: ≤0.8 dB	50:50 ±6.5%	850nm ±40nm, With the posibility of handling other wavelengths at higher attenuation	$40

ELECTRICAL HARDWARE AND COMPONENT SELECTION

Microcontroller Part

Selection: ESP32-WROOM-32E

- Have used prior in Real Time Systems (familiarity)
- Widely used for many examples and support
- PlatformIO C/C++ or Arduino libraries available – both with FreeRTOS for task scheduling

Family Name	Benefits	Drawbacks
STM-32	Wide use in industry	Harder to source development boards with fast turnaround
ESP-32	Familiarity with Use Easy C Libraries Wide use in industry Easy to source developme nt boards for testing	Can be slightly more expensive than competing solutions.
MSP430	Tends to be a cheaper solution Easy to source development boards for testing	Lesser Capabilities, Simple Nature.

SBC

Selection: Raspberry Pi 5 16GB

- Low power
- Easy to use I/O
- Familiarity from prior projects

Product	Advantages	Disadvantages
Raspberry Pi 5	Dual core ARM processor, enough for our uses Several SKUs for different amounts of RAM Official support for ROS2	Modern, less backtested support.
NVidia Jetson Nano	Standard and known formats	Relatively old Not used by many products.
Latte Panda	High compute power, more than enough for our uses.	High power requirements High heat generation High cost

IMU Part

Selection: Bosch BMI323

- More robust noise filtering leads to better signal for the application
- Microcontroller can easily handle software loading requirement

IMU Name	Advantages	Disadvantages
Bosch BMI270	Has ROS2 drivers Robust on-chip noise filtering Contains Titan Core for on-chip configuration	More complex, needs software loading on startup More development time due to complexity
Bosch BMI323	Has ROS2 drivers Robust on-chip noise filtering Newest solution, best community and manufacturer support	Does not allow on-chip configuration with Titan Core
TDK MPU6000	Has ROS2 drivers Large back catalog of prior support Lower default frame times, easier to filter in post-processing	Older, falling out of favor (some drivers must be backported) Little to no on-chip noise filtering

Audio - Speaker

Selection: 8 Ohm 1W Voice Range Speaker

- Range suited for speech cues
- Higher impedance at sufficient volume within a grocery store environment
- Low power consumption

Product	Nominal Impedance (Ohms)	Rated Power (W)	Sensitivity (dB SPL)	Frequency Range (Hz)
2.5 Inch Full Range Speaker	4	3	88.5	200-20000
1.1 Inch (28 mm) 8 Ohm Voice Range Speaker	8	8	86	650-6000
1.5 Inch (40 mm), 8 Ohm Voice Range Speaker	8	1	81	350-6000

Audio - Driver

Selection: Class D (PAM8302AASCR)

- Greatest efficiency
- Lightest weight
- Capable of supporting the 8 Ohm 1 W speaker (rated for 2.5 W and at least 4 Ohm)

Amplifier Class	Typical Efficiency	Pros	Cons
A	~15-35%	No possibility of crossover distortion.	Inefficiency = heat Single ended designs prone to hum and higher levels of distortion.
B	~70%	Relatively high efficiency.	Potential for significant amounts of crossover distortion and compromised fidelity
A/B	~50-70%	More efficient than Class A. Relatively Inexpensive. Crossover distortion can be rendered moot.	Efficiency is good, but not great.
G & H	~50-70%	Improved efficiency over Class A/B.	Costlier than Class A/B but higher power levels are achievable in a smaller form factor.
D	>90%	Best possible efficiency Light weight.	Pulse width modulators operating at relatively low frequencies can compromise high frequency audio reproduction. Some designs produce varying sound quality depending on speaker load.

Haptic - Motor and Driver

Selection: Coin ERM

- Very cheap, including common DC drivers (DRV2605L)
- Supports libraries for multiple modes
- Strong haptic feedback
- Precision doesn't matter much
- Easy to integrate with the shopping cart handlebar

Motor Type	Mechanism	Drive Signal	Power Consumption	Haptic Feedback	Size	Cost
ERM	Rotation of an unbalanced mass	DC Voltage	Moderate	Strong but imprecise	Larger than LRA and Piezo	Low
LRA	Linear oscillation of a mass on a spring	AC Voltage at resonant frequency	Low	Moderately strong, more precise than ERM	Compact	Moderate
Piezo	Deformation of piezoelectric material	AC Voltage at highfrequencies	Low to moderate	Very high precision	Ultra-compact	High

Power Source Technology

Selection: LiFePO4 (Li-ion) Battery

- Portable, reliable power
- Increased weight manageable due to cart chassis
- System requirements: **Maximum 35W, 7A peak current draw**
- Products have additional capacity with included over-current, over-discharge, and overcharge cases

Battery Technology	Energy Density	Output Capacity	Cost	Rechargeable Cycle Life	Safety	Potential Risks
LiFePO4	High	Moderate	Moderate	500-5000 cycles	Moderately safe with protection circuits	Overheating, thermal runaway without protection
LiPo	Very high	High	Moderate	300-500 cycles	Less safe, prone to swelling and puncture	Thermal runaway, risk of swelling without protection circuitry
NiMH	Moderate to low	Low	Low	Up to 1000 cycles	Very safe	Bulky and heavy

Product	Voltage (V)	Capacity (Ah)	Cost	Safety
XZNY LiFePO4	12.8	10	$29.99	Built-in BMS
NERMAK LiFePO4	12.8	10	$33.99	Built-in BMS
BtrPower LiFePO4	12.8	8	$29.99	Built-In BMS

Voltage Regulators

Selection: LM2679SX-ADJ Switching Regulators

- High efficiency, low heat robust regulators
- Supports maximum current draw (5A) and battery input voltage (12.8V)
- Multiple regulators used for various component demands (adjustable output voltage model)

Regulator Type	Efficiency	Heat Dissipation	Noise	Cost	Applications
Switching	High (~90%)	Low	Higher	Higher	High-power, high-efficiency
Linear	Low (~30-50%)	High (excess power dissipated as heat)	Very low (ideal for sensitive circuits)	Lower	Low-power, low-noise

Product	Input Voltage Range (V)	Output Current (A)	Output Voltage Range (V)
LM2679SX-ADJ	8-40	5	1.21-37
LM2576S-ADJ	4-40	3	3.3-37
TPS543521	3.8-18	5	0.6-17.

SOFTWARE COMPARISON AND SELECTION

Input Interface

- USB
  - Cameras
  - USB Video Class Compliant
- WiFi (IEEE 802.11)
  - Grocery List Input
  - Main web server hosted on SBC, with results passed to MCU via API server for processing.
- I2C
  - IMU

Control Output Scheme

Selection: Haptic + Speaker

- Gives user the most agency
- Extremely easy to implement as opposed to autonomous motor control or full visualization

Name	Ease of Integration	Advantages	Disadvantages
Haptic	Easy	Can be tuned to be extremely intuitive Very easy to implement Gives user agency	Not extremely robust, allows for collision risks
Speaker	Medium	Easy to give detailed instructions without having to visualize or make motor control scheme	A bit harder to implement than the buzzer
Video Indication	Very Hard	Can be extremely intuitive Gives user agency Customizable	Extremely difficult to design UI and implement software Non-welcoming of completely blind people
Autonomous Control	Very Hard	Extremely robust	Extremely hard to develop

Inter-Process Communication

Selection: DDS

- ROS2 runs DDS under the hood
- Provides a lot of needed infrastructure

DDS Implementation	Latency	Scalability	Ease of Implementation
DDS	Moderate	High	Moderate
MQTT	High	Moderate	Moderate
Custom Rust/C++	Low	Low	Difficult

SLAM Implementation Comparison

Selection: RTAB-Map

- High amount of infrastructure for stereo-vision-based SLAM
- Holds its own planner, so no need for Nav2 interfacing

SLAM Implementation	Available Infrastructure	ASV Interface Quality	NAV2 Interface Quality	Available Documentation
RTAB-Map	High	High	Moderate	High
Slam-toolbox	High	Low	High	High
ORB3_SLAM	Moderate	High	Low	Low

PCB DESIGN

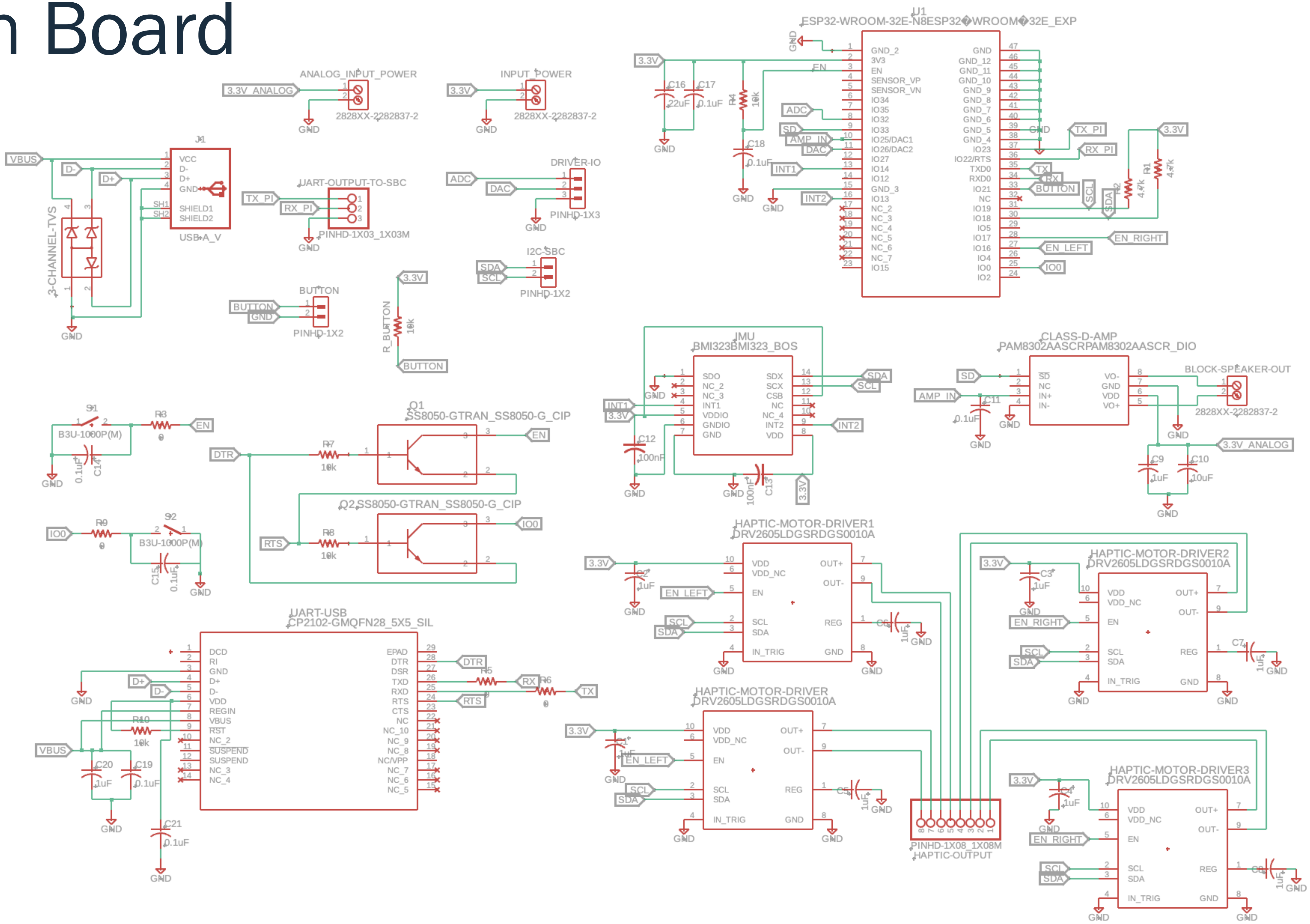
PCB Design Choices

Main Board:
- ESP32, UART-to-USB module (CP2102), IMU, speaker amplifier, haptic motor drivers.
- Contains input/outputs to the SBC, output connectors to the peripherals devices (speaker/haptics), input power and programming connections.
- Separation of analog components and lines (DAC, ADC, speaker amplifier) from digital components and lines.

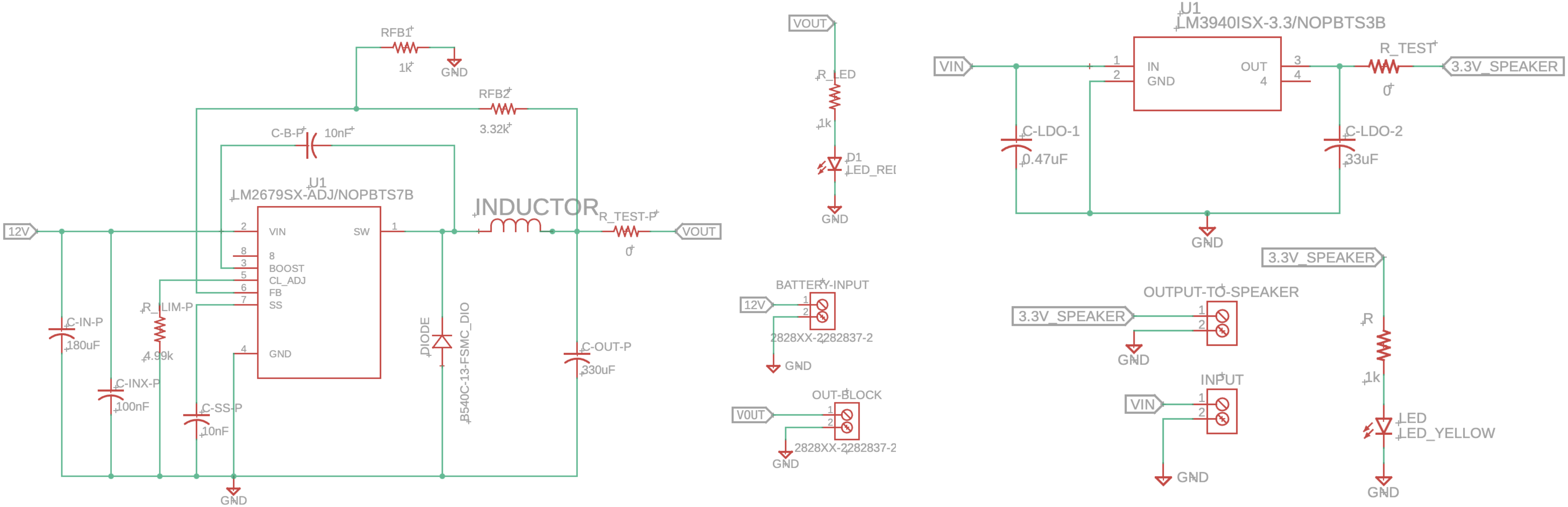
Power Daughterboards:
- Adjustable switching regulator for both 5V and 3.3V output for various components and separation of digital and analog supplies.
- Input from battery, output to boards.
- 3.3V 1A LDO as a secondary power supply for analog components.
- Easy to replace in the event of failure or burnt-out boards. On-board status LEDs.

Laser Diode Driver Daughterboard:
- Laser diode driver, input/output to MCU for laser modulation and current diagnostics, separate input power supply and output to laser diode terminals.
- Dedicated board for analog and thermal management. Closer positioning to the laser diode mount.

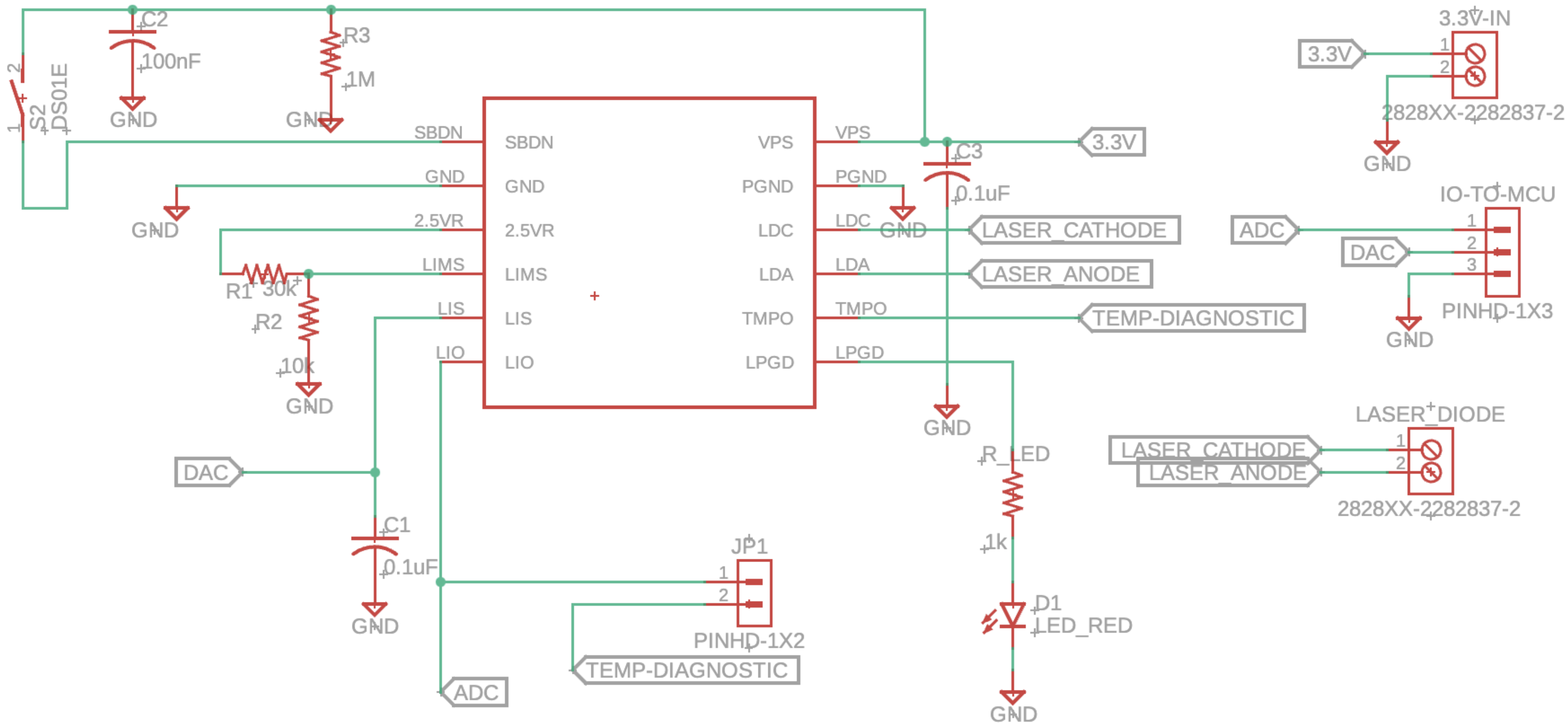
Main Board


U1
ESP32-WROOM-32E-N8ESP32�WROOM�32E_EXP
ANALOG_INPUT_POWER
2828XX-2282837-2
INPUT_POWER
2828XX-2282837-2
J1
USB-A_V
3-CHANNEL-TVS
UART-OUTPUT-TO-SBC
PINHD-1X03_1X03M
DRIVER-IO
PINHD-1X3
I2C-SBC
PINHD-1X2
BUTTON
PINHD-1X2
R_BUTTON
IMU
BMI323BMI323_BOS
CLASS-D-AMP
PAM8302AASCRPAM8302AASCR_DIO
BLOCK-SPEAKER-OUT
2828XX-2282837-2
S1
B3U-1000P(M)
S2
B3U-1000P(M)
Q1
SS8050-GTRAN_SS8050-G_CIP
Q2 SS8050-GTRAN_SS8050-G_CIP
UART-USB
CP2102-GMQFN28_5X5_SIL
HAPTIC-MOTOR-DRIVER1
DRV2605LDGSRDGS0010A
HAPTIC-MOTOR-DRIVER2
DRV2605LDGSRDGS0010A
HAPTIC-MOTOR-DRIVER
DRV2605LDGSRDGS0010A
HAPTIC-MOTOR-DRIVER3
DRV2605LDGSRDGS0010A
PINHD-1X08_1X08M
HAPTIC-OUTPUT

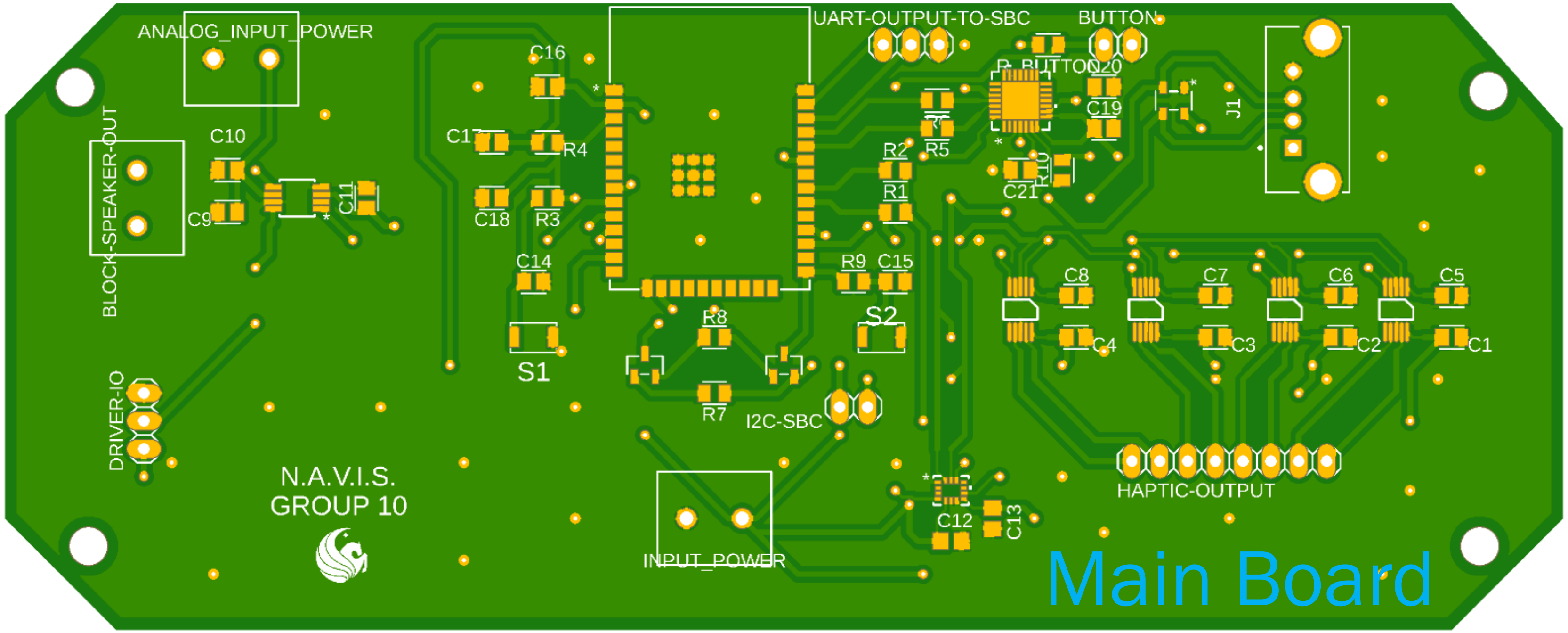
Switching Regulator and LDO Daughterboards



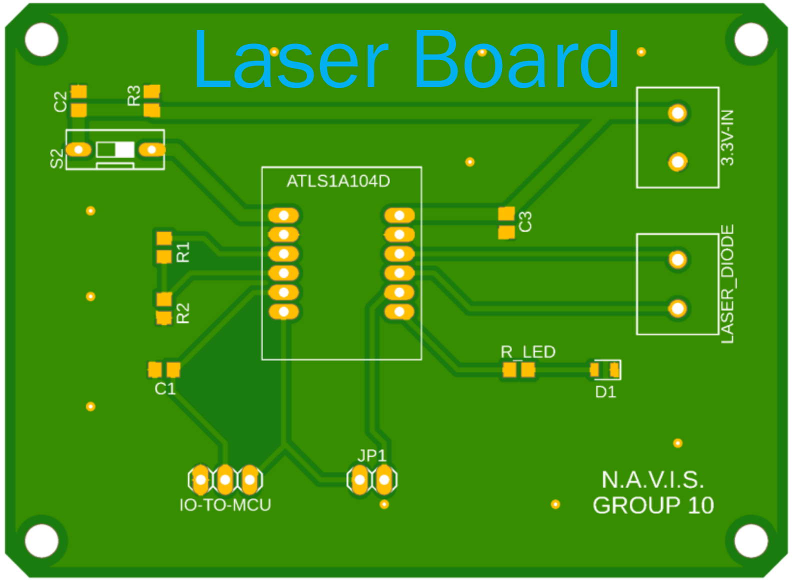
Optical Driver Board



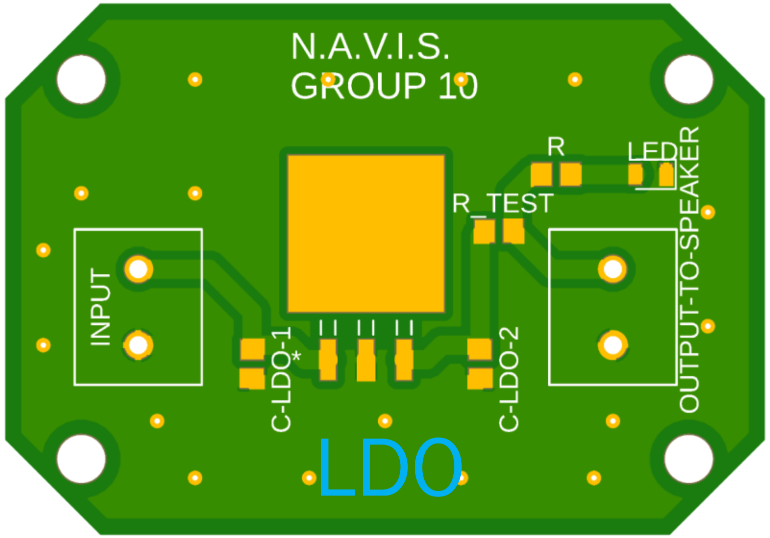
PCB Layouts



Main Board

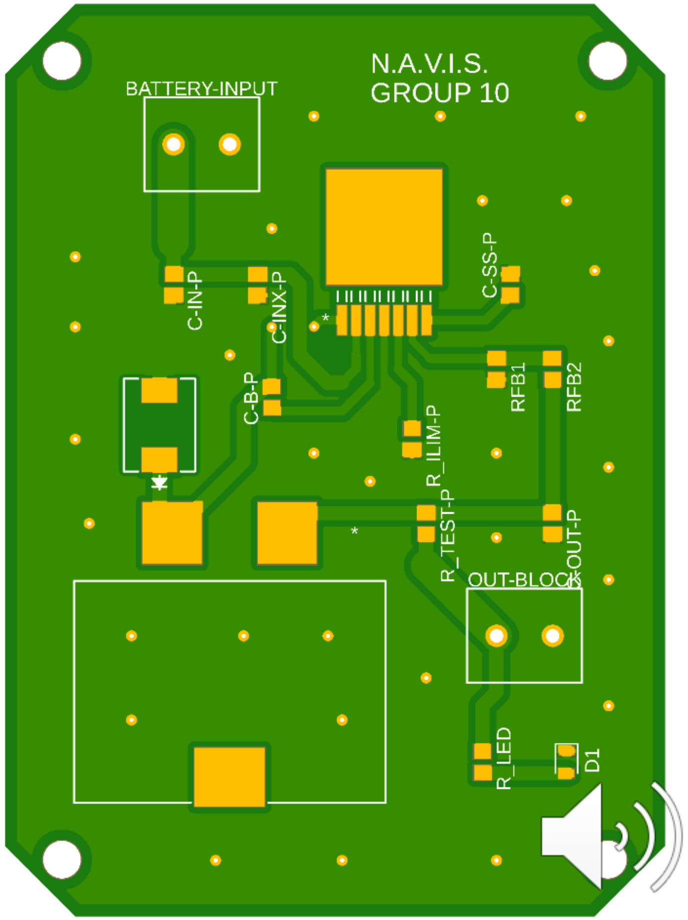


Laser Board



LDO

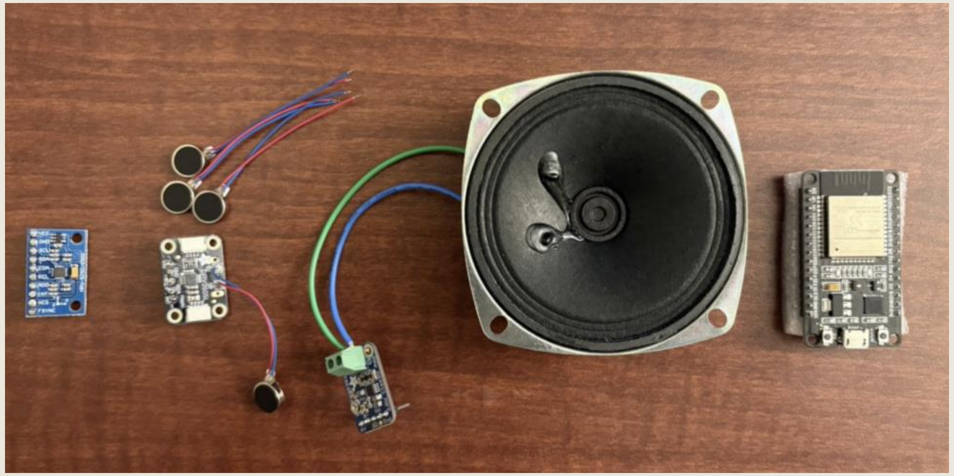
Switching Regulator

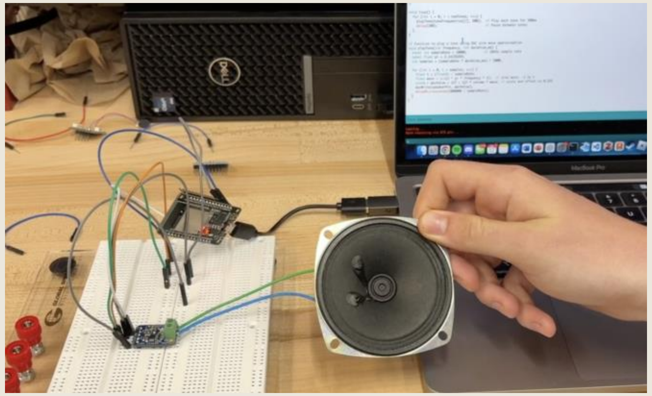


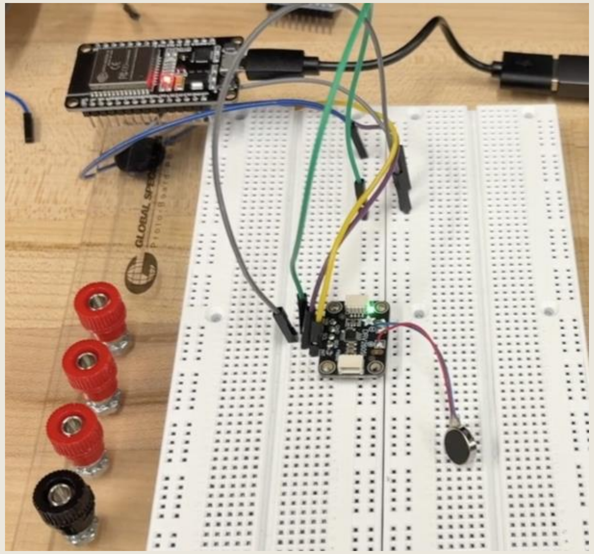
PROTOTYPE AND TESTING

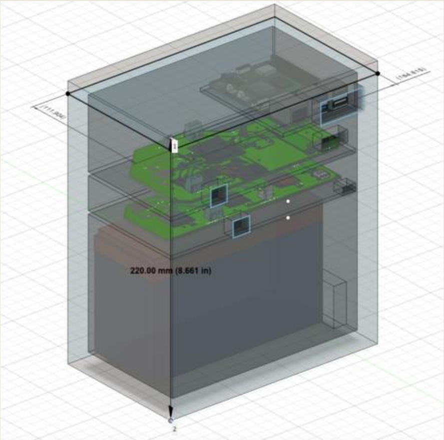
Preliminary Electrical Component Testing

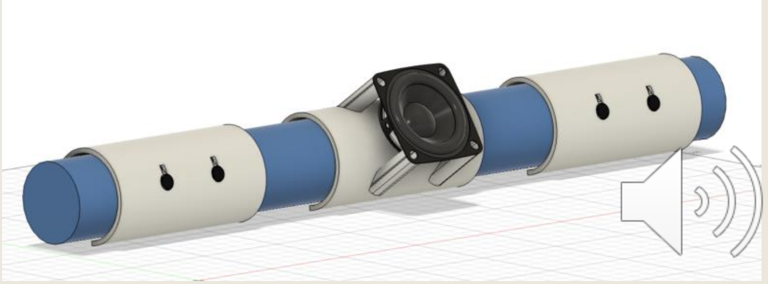
- Acquired peripheral components and designed initial CAD housing/mounts.
- Completed initial proof of concept tests with prototyping boards for major hardware components with MCU and Raspberry Pi.
- Tested haptics with various vibrational patterns, speakers with a range of different tones and outputs, and IMU for reliable positioning data.
- Checked communication between peripherals, MCU, and SBC.











PCB Testing

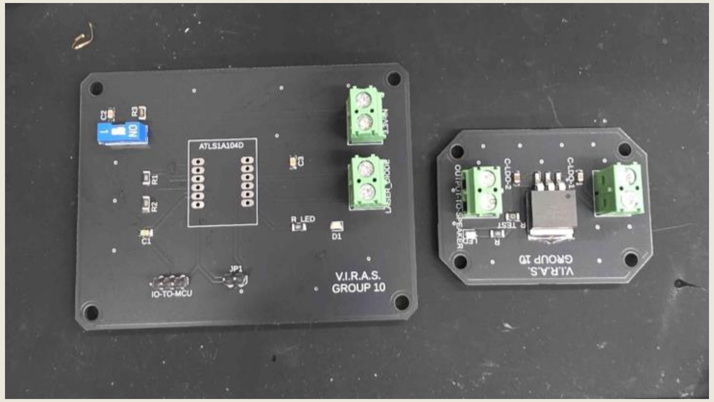
PCBs and components ordered and received, initially building started.

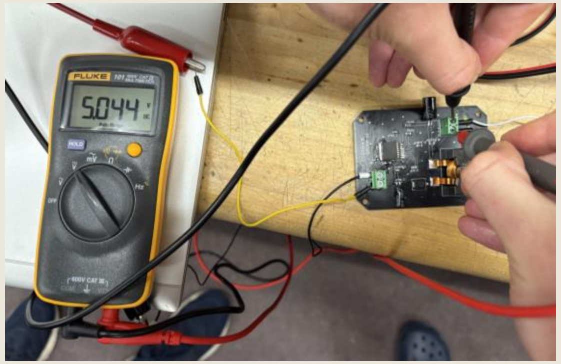
Successes:

- Switching regulator successfully outputs 5V at 5A.
- LDO successfully outputs 3.3V at 1A.
- Optical board built and ready for testing.

Challenges:

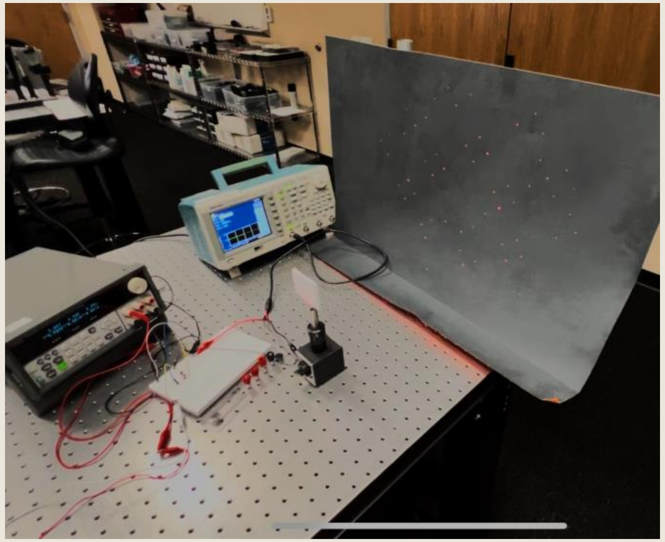
- Incorrect footprint for electrolytic capacitor.
    - *Solution: Soldered matching electrolytic capacitor on pads – results in a successful output.*

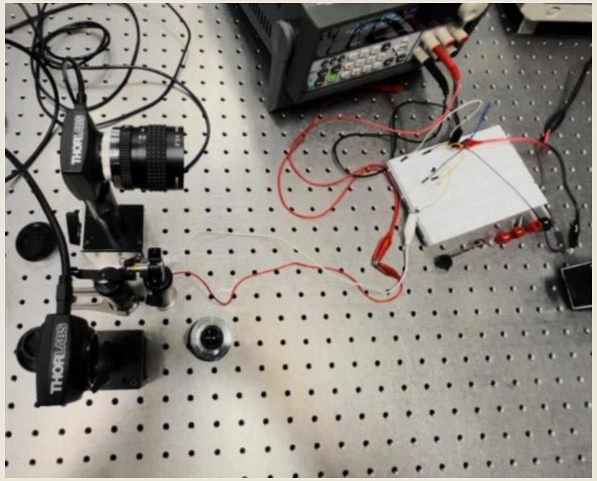


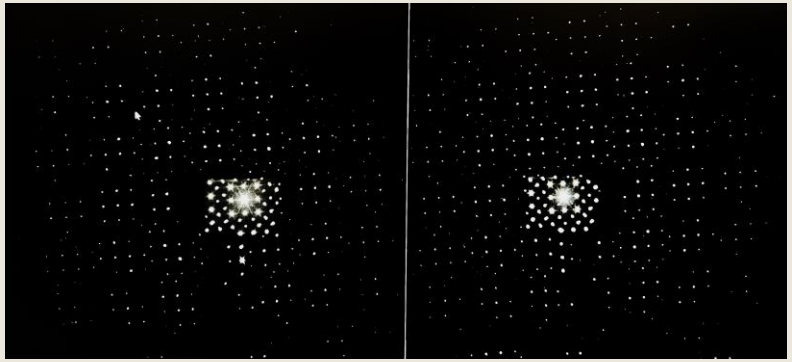


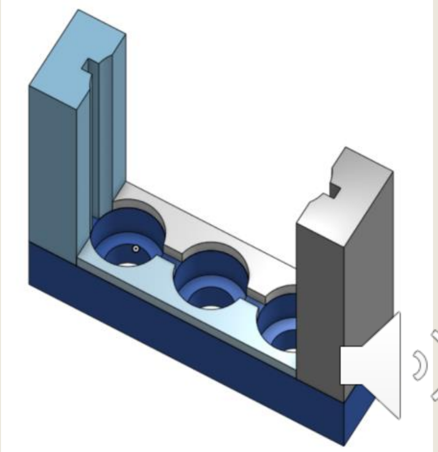
Preliminary Optical Component Testing

- Acquired rudimentary components
- Completed proof of concept testing using a preliminary MATLAB code for disparity calculations
- Pigtailed laser diode was damaged due to direct connection to the current source without implementing a proper protection circuit.
- Built preliminary testing bench for bought CMOS cameras for stereo vision calibration









Software Prototype and Testing - SBC (Navigation Stack)

- Stereo Vision Calibration
  - The driver and depth image calculations are implemented, but we need to go through calibration testing for performance differences with things like frame syncing, fps, and resolution
- SPLAM (Simultaneous Planning, Localization, and Mapping)
  - Almost all of the algorithms needed for SPLAM are built into the RTAB-Map library, so implementation has been easy
  - That said, there needs to be a large amount of time dedicated to tuning the SPLAM parameters

Administrative Content - Budget

Components / Subsystem	Target Price
System Enclosure	$50
Optics (Laser, Driver, Fiber, and Cameras)	$600
Electrical (excluding PCBs and SBC)	$100
PCBs	$125
Single Board Computer	$125
Total	**$1000**

Administrative Content – Work Distribution

Team Member	Responsibilities
Matias Barzallo	Active Stereo Vision Optical Design and Development
	Laser Diode Electrical Integration
	IR CMOS Camera Electrical Integration
Michael Castiglia	Project Manager and Administrative Content
	Microcontroller Software and Integration
	Sensor Driver and Integration
	Web App Design and Development
	High Brain - Low Brain Board Communications
Aden McKinney	Autonomous Navigation Stack Design and Development
	Control Output Software Development
Pavan Senthil	Power System Design and Implementation
	PCB Design
	Peripheral Hardware Integration
	CAD and Housing Development

Plan for Completion

PCB
- Build and test main board (load and sensors) and backup versions of all boards.

Housing
- Print CAD housing and mounts with updated PCBs, hardware, and wiring.
- Fit components together and test with mounting on a physical cart.

Optical
- Calibrate and test laser diode, collimating lens, and DOE.
- Implement 850nm Bandpass filter into camera lens module.

Device Testing
- Create mock store environment for device testing using the UCF library aisles.
- Conduct trials runs to assess device performance and success rates.

Software
- Development of protocols for mapping and calibration for when electronics testbed is ready.
- Verification of programs such as control calculation and performance tuning of SPLAM parameters.




THANK YOU!