SAFEPADS: Smart Animal Fencing and Emergency Predator Alert and Detection System

Senior Design II

Group 9

Meet the Team

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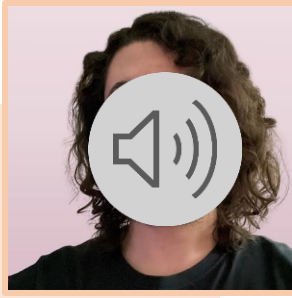
Overall Project Motivation



Why Smart Collars?

Many pet owners deeply care about the safety and happiness of their pets but cannot continuously monitor them due to other obligations. Smart collars offer a practical technological solution to promote pet safety and provide pet owners with peace of mind while away from home.

Common Smart Collar Features:

- GPS
- Geofencing
- Training Assistance
- Activity Tracking
- Health Monitoring

SAFEPADS combines many desirable competitor features into one product

Gaps in Current Market

- Lack of mechanism to defend unsupervised pets from predators
  - Current solution is mechanical device with spiked protrusions (no smart features)
  - SAFEPADS will include a feature that defends pets in instances where they may be in danger
- Lack of integrated indoor invisible fence system
  - Available as a standalone product (no smart features)
  - SAFEPADS will include an indoor location/fencing system to protect pets from hazards within the home and locate pets in areas where using stationary security cameras is not feasible, cost-effective, or desired

Basic Goals

- Location tracking
- Geofencing via vibration feedback
- Manual vibration feedback activation for training
- Activation of defense mechanism on detection of potential predator in pet's environment
- Owner SOS notifications
- Indoor location/fencing system detects when collar has passed point of installation
- Wireless data transmission to app

Advanced Goals

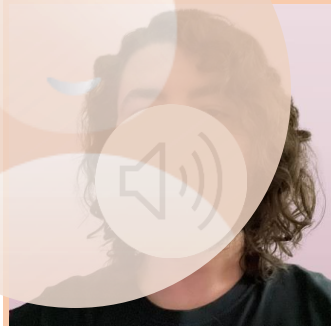
- Further training of image processing model to reduce false positives
- Indoor location/fencing system differentiates between pets

Stretch Goals

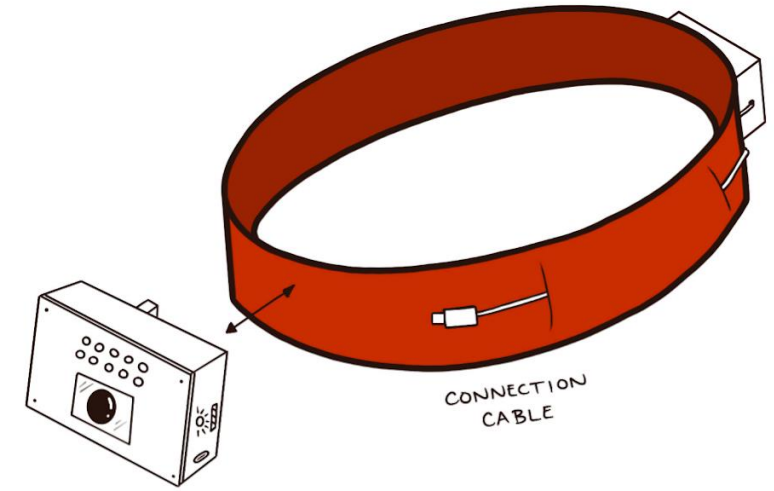
- Multi-platform app
- Use indoor location/fencing system to track pet speed and indoor activity
- Software distinguishes between low-danger and high-danger predator encounters

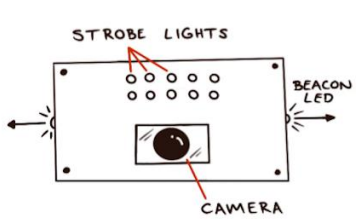
Objectives

- A wide field-of-view camera with image processing software
- Using the camera to detect predators and activate a defense mechanism
- Live GPS location and Geofencing features
- Indoor location system
- A main GUI application for the user



Design





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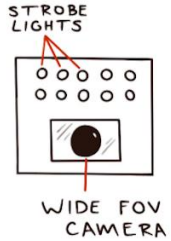

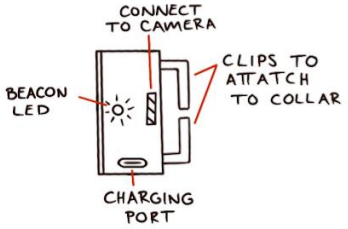

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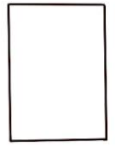

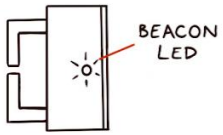

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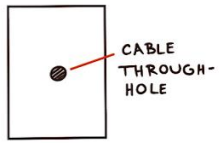
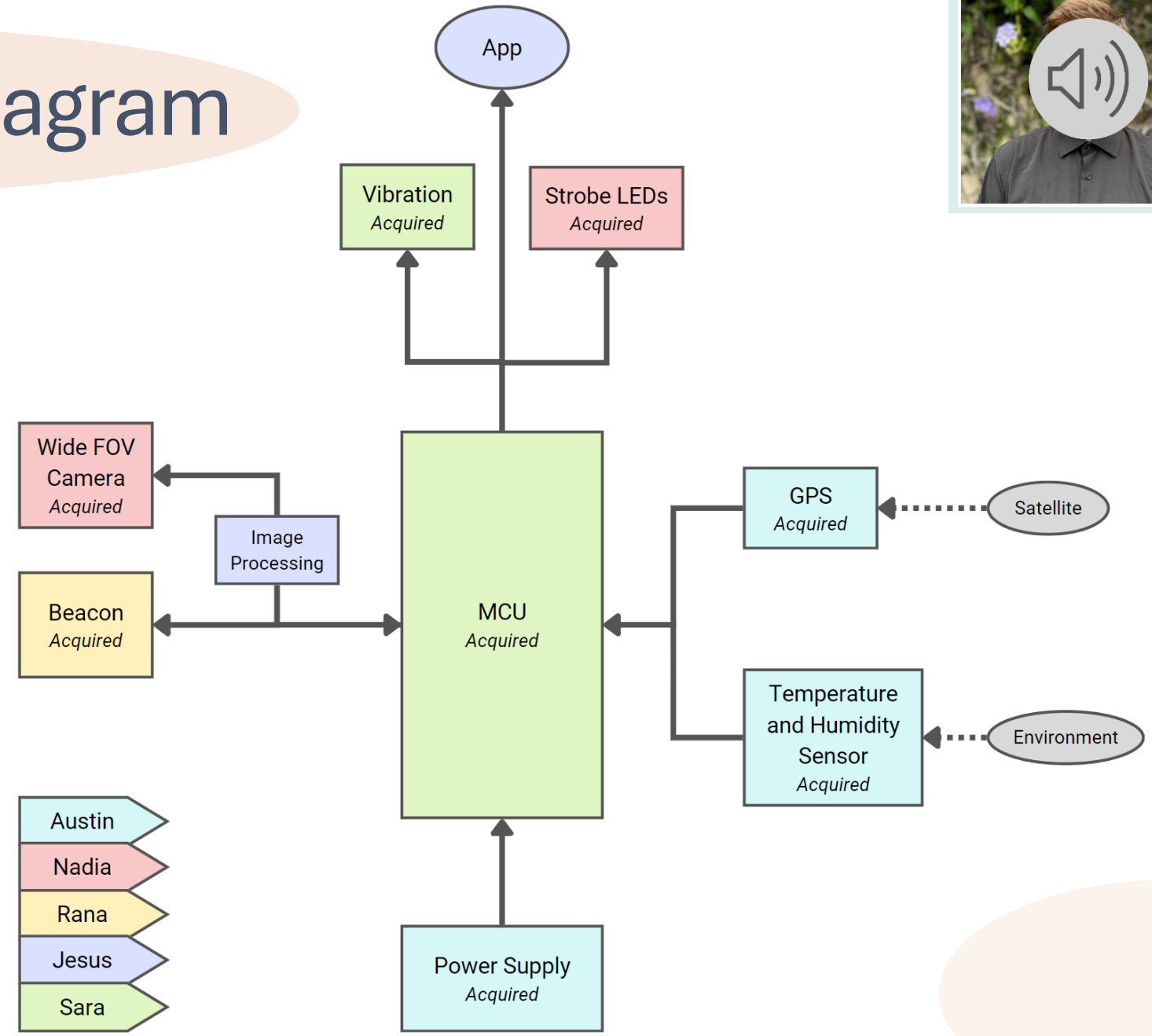


Hardware Block Diagram



Specifications and Requirements

Component	Parameter	Specification
Temperature Sensor	Temperature detection in ℃	2 ℃.
Wireless Transmission	Upload speed for general information	< 10 minutes
Power Supply	Length of rechargeable battery life	> 1 hour
GPS	Geofencing/location tracking update time	Update location at least every 30 seconds
DC Motor	Vibration	~150 Hz
Wide Field of View Camera	Angle	≥ 180° field of view
Indoor Fencing Receiver Lens System	Angle	≥ 90° field of view
Indoor Fencing Receiver Lens System (cont.)	Accuracy	≥ 90%
White LED	Strobe light duration	1 minute

Hardware Comparison and Selection

Microcontroller Selection

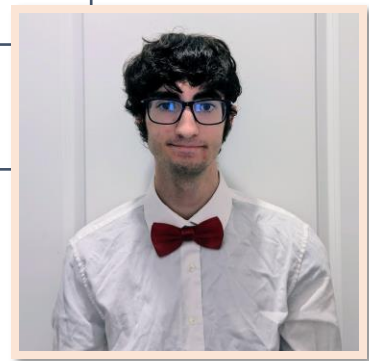
- Goal: Allow the collar to operate with and interact with I/O devices.
- Priorities:
  - Compact physical size
  - Integrated WiFi module
  - Ease of programming
  - High processing power
  - Low cost

Component	Size	WiFi Module?	Num. of Bits	Bit Rate	Num. of Power Mode Options	Price
MSP430	7mm x 7mm	No	16	12Mbps	4	$10
MSP432	9mm x 9mm	No	32	16Mbps	5	N/A
Arduino Nano (ATmega328P)	7mm x 7mm x 1.2mm	No	8	2Mbps	4	$12
ESP32	5mm x 5mm x 0.850mm	Yes	32	150Mbps (WiFi), 4Mbps (Bluetooth)	5	$10
ESP8684	4mm x 4mm x 0.850mm	Yes	32	72.2Mbps (WiFi), 2Mbps (Bluetooth)	4	$8
Raspberry Pi	7.75mm x 7.75mm	Yes	32	62.5Mbps	0	$50
Particle Photon	14.60mm x 16.60mm	Yes	32	N/A	0	$19

Temperature and Humidity Sensor Selection

- Goal: Provide pet owners with a warning when their pet is in an environment outside a recommended temperature range for an extended period of time.
- Priorities:
  - Temperature accuracy within ±2°C
  - Relative humidity accuracy within ±10%
  - Low current consumption
  - Small size
  - Low cost

Component	Accuracy	Current Consumption	Size	Price
DHT-11	±2°C and ±5% relative humidity	0.3mA	15.5mm x 12mm x 5.5mm	$5
DHT-22	±0.5°C and ±2% relative humidity	1.5mA	14mm x 18mm x 5.5mm	$10
TMP36	±2°C	50µA	3.5mm x 4.6mm x 19mm	$3
LMT84	±0.9°C	5.4µA	4.3mm x 3.5mm x 4.3mm	$2
SHT31	±0.2°C and ±2% relative humidity	1.5mA	2.5mm x 2.5mm x 0.9mm	$6
HIH-4030	±3.5% relative humidity	200µA	4.17mm x 8.59mm x 2.67mm	$21
HDC2010	±0.2°C and ±2% relative humidity	550nA	1.5mm x 1.5mm x 0.675mm	$4



Global Positioning System Selection

- Goal: Allow pet owners to monitor where their pet has been throughout the day and to provide geofencing capabilities.

- Priorities:
  - Accuracy within ±5m
  - Low current consumption
  - Small size
  - Low cost
  - Easy to test and program

Component	Accuracy	Current Consumption	Size	Price
PA1616D	±3m	29mA	16mm x 16mm x 6.7mm	$20
PA1616S	±3m	20mA	16mm x 16mm x 4.7mm	$25
NEO-M9N-00B	±2m	36mA	15.9mm x 12.2mm x 2.4mm	$27
L96-M33	±2.5m	19mA	14mm x 9.6mm x 2mm	$13

Battery Selection

- Goal: Provide an appropriate amount of power to all components on the pet collar.

- Priorities:
  - High energy density
  - Low cost
  - Ability to supply 3.3V to system
  - Small size
  - Ability to be recharged

Component	Typical Output Voltage	Energy Density	Price (400 mAh)
Lithium-Ion	3.7V	250 Wh/kg	$7
Nickel Metal Hydride	1.2V	90 Wh/kg	$2
Nickel Cadmium	1.2V	60 Wh/kg	$1.5

Vibration Motor Selection

- Goal: Allow pet owners to indicate to their pet when they are exhibiting an undesirable behavior without the use of shocks.

- Priorities:
  - Safe
  - Variable intensity
  - Small size
  - Operating voltage ≤ 3.3V

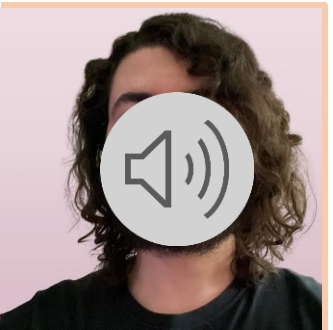
Component	Operating Voltage	Dimensions (diameter x height)	Adjustable Intensity?	Price
Vybronics Z-Axis LRA Coin VM (VG1040003D)	0.14 V - 3.54V	10mm x 4mm	Yes	$3.71
Adafruit 1201 Vibration ERM Motor	2V - 5V	10mm x 2.7mm	Yes	$1.95
SparkFun Solenoid	2V - 5V	4mm x 20mm	Yes	$5.50
Kingstate KPEG130 Piezoelectric Transducer	4V - 28V	30.2mm x 7.5mm	Yes	$2.27

Software Comparison and Selection

High priority considerations:

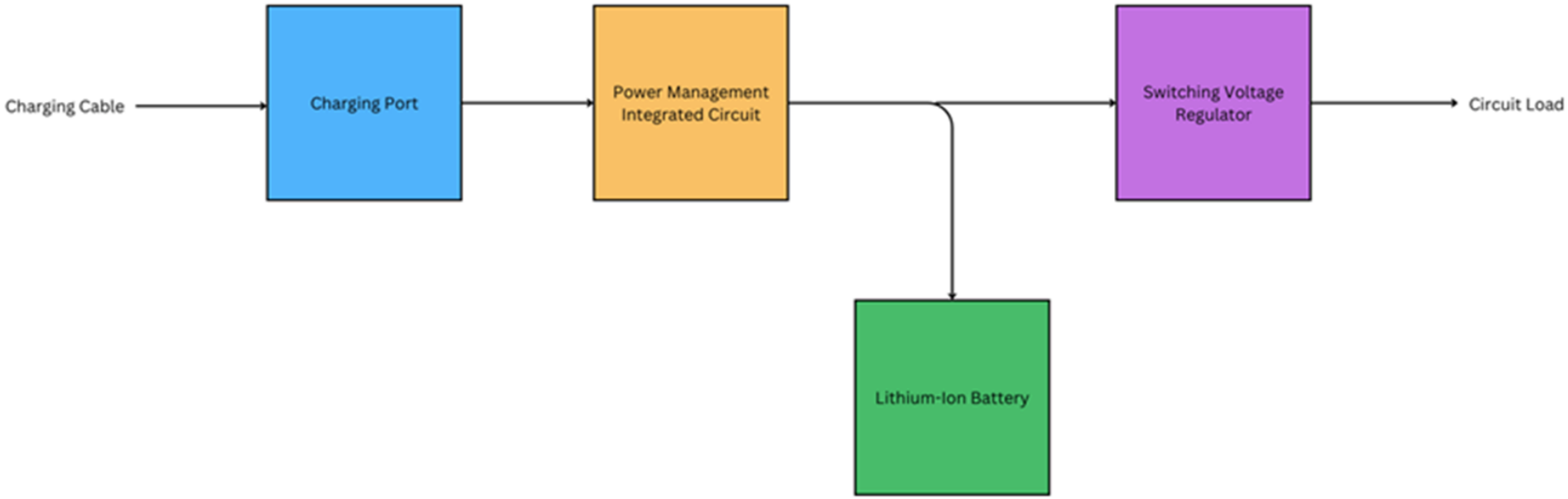
- Experience
- Image Processing
- Speed
- Integrability
- Readability

	Programming Language			
	Java	**Python**	**C**	**Swift**
Level	High	High	Low	High
Speed	Low	Low	High	Mid
Power Consumption	Low	High	Low	Mid
IDE Availability	Yes	Yes	Yes	Yes
Ease of Production	Mid	High	Low	Mid
Image Processing Support	Yes	Yes	Yes	Yes
Readability	Low	High	Low	High
Experience	Yes	Yes	Yes	No

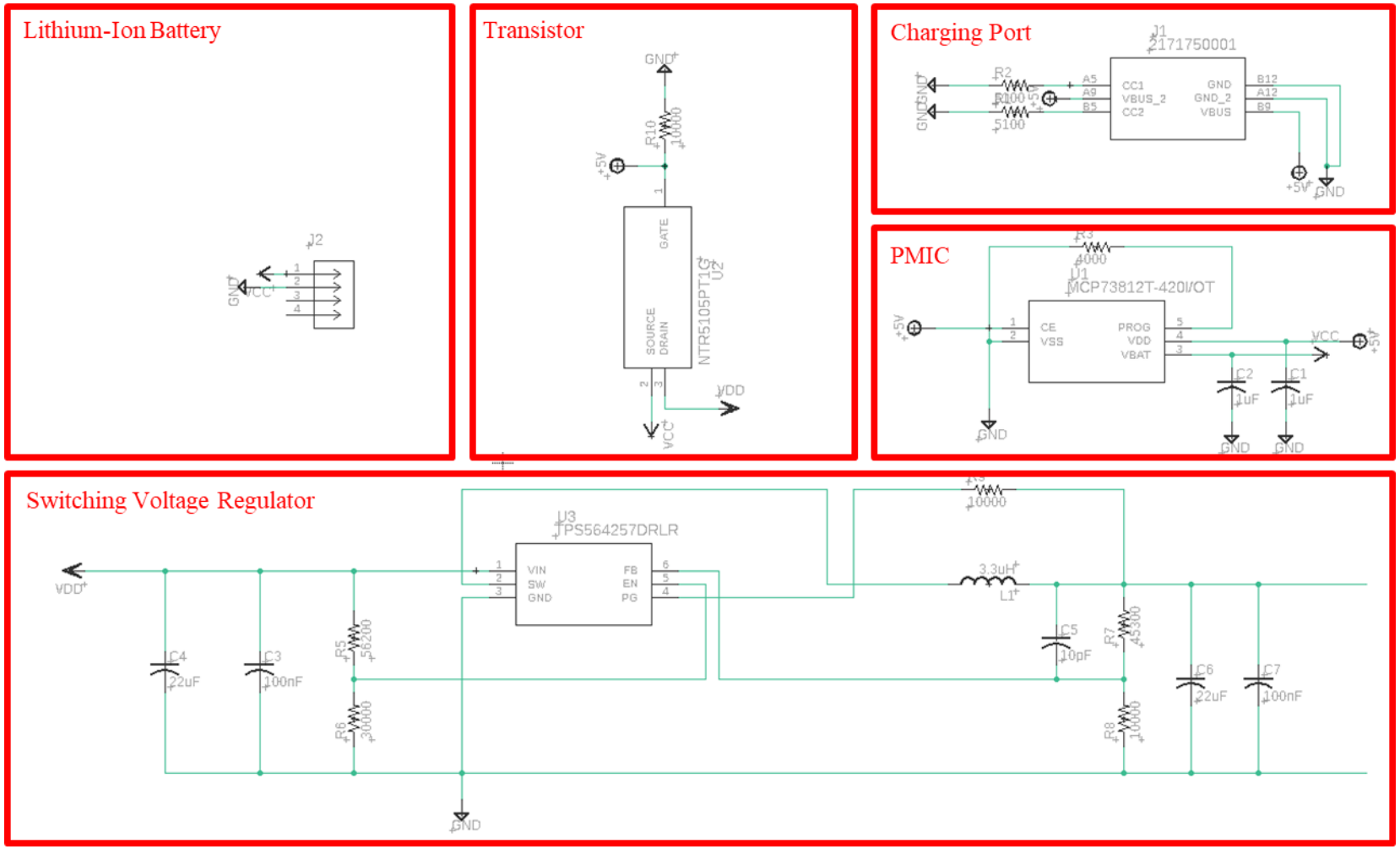


Power Supply Subsystem

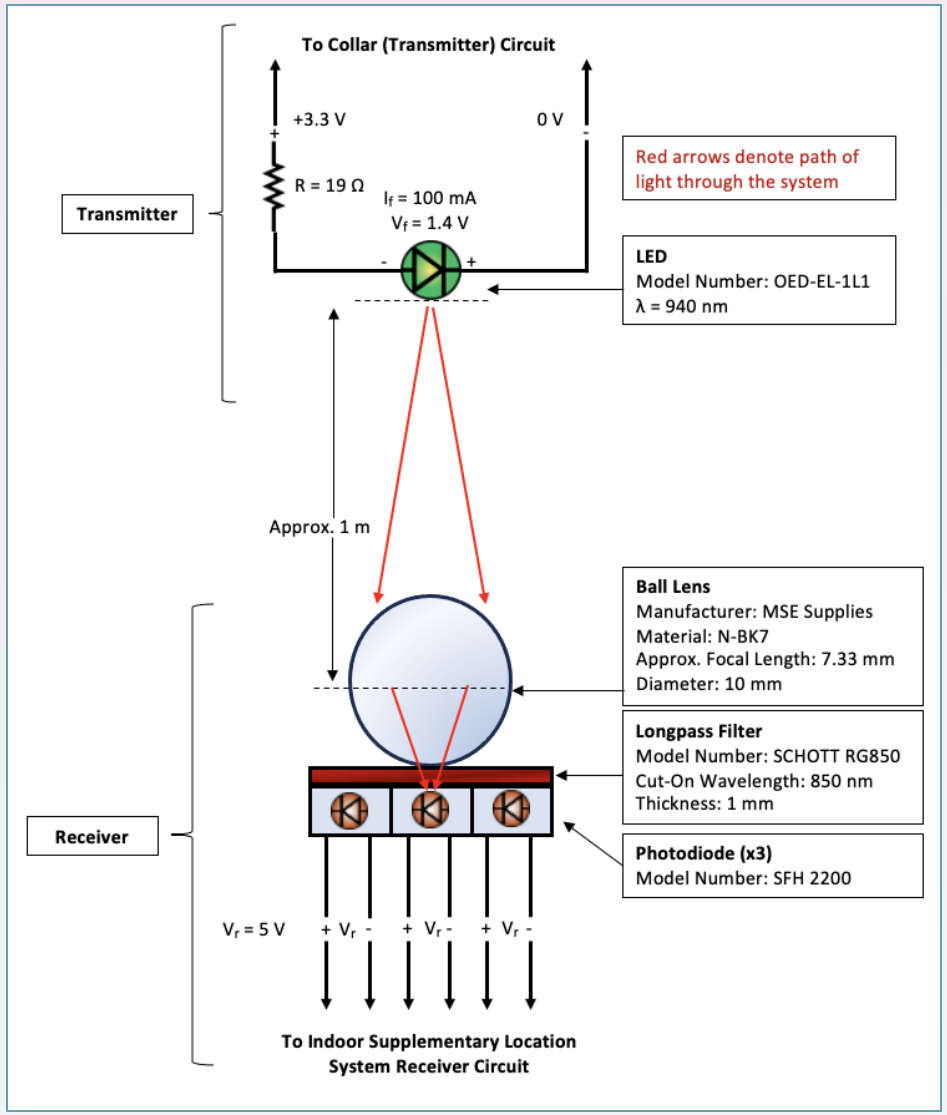
- Goal: Enable charging and supply an appropriate amount of power to the entirety of the circuit

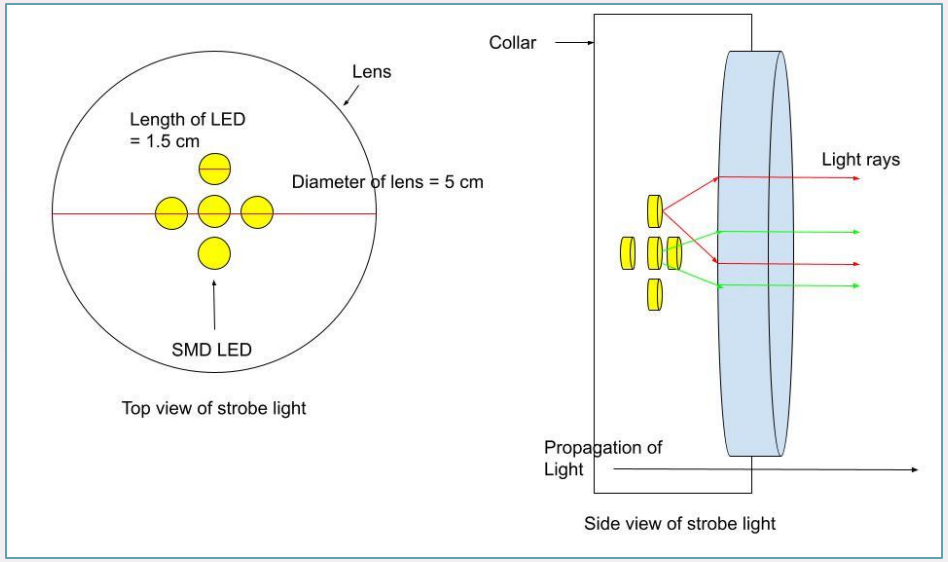


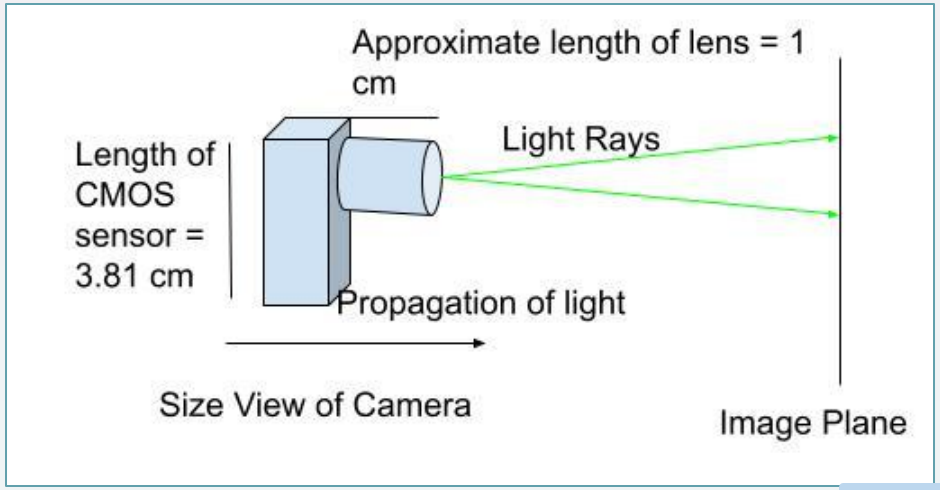
Power Supply Subsystem



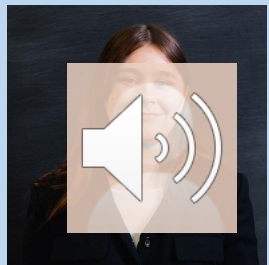
- PMIC: Charges battery at a maximum rate of 250 mA.
- Switching Voltage Regulator: Outputs 3.3 V at 93.8% energy efficiency.
- Transistor: Included to disable rest of device while charging.





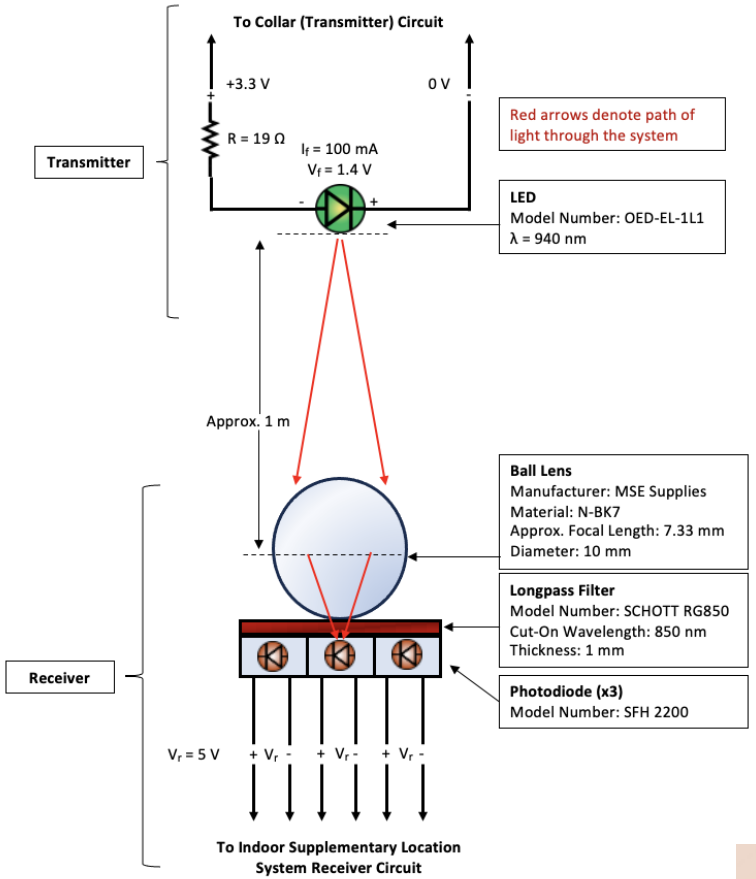


Optical Schematics



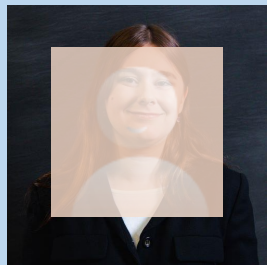
Indoor Location and Fencing System

- Overall Design:
  - Transmitter-receiver pair detects when collar has passed the point-of-installation
    - Once — pet entered room
    - Twice — pet exited room
  - Receiver receives power separately and contains separate microcontroller—transmits detection data over Wi-Fi to software
    - Software activates collar vibration feedback
  - Frequency of pulsed light source uniquely identifies collar
    - 10 kHz to 20 kHz range
  - Specifications: ≥ 90° field of view, 1 meter working distance, 90% accuracy, transmitter light source wavelength > 900 nm



Transmitter Light Source Selection—Wavelength (λ)

System must not be susceptible to environmental noise	Typical household lighting emits mostly in the 400-750 nm range Incandescent lights emit infrared light but have been phased out of market
System should be compatible with cost-effective optical components	NBK-7 glasses accept ~350 nm < λ < ~2000 nm
Wavelength must not upset animal's circadian rhythm	Dog vision is confined to the visible region Photoreceptor pigments in cats' eyes may be sensitive to light with wavelengths as long as 900 nm
Therefore, 900nm < λ < 2000 nm	



Transmitter Light Source Selection

	Light-Emitting Diode (LED)	Laser Diode
Advantages	•Eye-safe in required wavelength range •Inexpensive	•Coherent, highly directional source •Can propagate for long distances without significant change in beam size/beam divergence angle •Narrower spectral bandwidth
Disadvantages	•Incoherent source •Commonly includes unspecified focusing optics in packaging	•Restricted to use of eye-safe wavelengths within acceptable exposure limits •Expensive

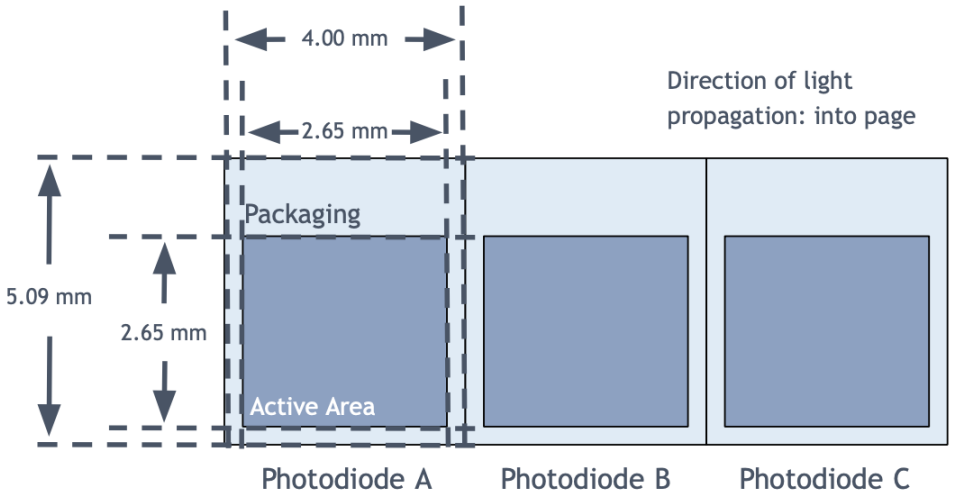
Component	Emission Wavelength	Maximum Output Power (Approximate)	Power Consumption	Price
ML925B45F	1500 nm ± 0.75 nm	5 mW	33 mW	$56.48
IR333-A	940 nm ± 22.5nm	8.11mW	140 mW	$0.75
OED-EL-1L1	940 nm ± 22.5nm	11.4 mW	140 mW	$0.43

Photodetector Selection

	Photoresistor	Photodiode (Reverse-Biased)
Advantages	•High level of photoconductive gain	•Linear response to incident irradiance •Fast response time — performs well with high-frequency modulation •Inexpensive with sensitivity at 940 nm
Disadvantages	•Limited ability to respond to high-frequency modulation •Logarithmic response to incident irradiance •Not widely available with sensitivity at λ > 900 nm	•Lesser responsivity than photoresistor

Component	Responsivity at 940 nm	Rise Time (V_r = 5 V)	Fall Time (V_r = 5 V)	Dark Current (V_r = 10 V)	Active Area	Price
VEMD2704	0.78 A/W	70 ns	70 ns	0.03 nA	1.51 mm^2	$0.83
SFH 203 PFA *measurement taken with Vr = 20 V	0.62 A/W	5 ns*	5 ns*	1 nA*	1 mm^2	$1.00
BPW 34 S	0.67 A/W	20 ns	20 ns	2 nA	7.02 mm^2	$1.13
SFH 2200	0.70 A/W	40 ns	40 ns	1 nA	7.02 mm^2	$1.39

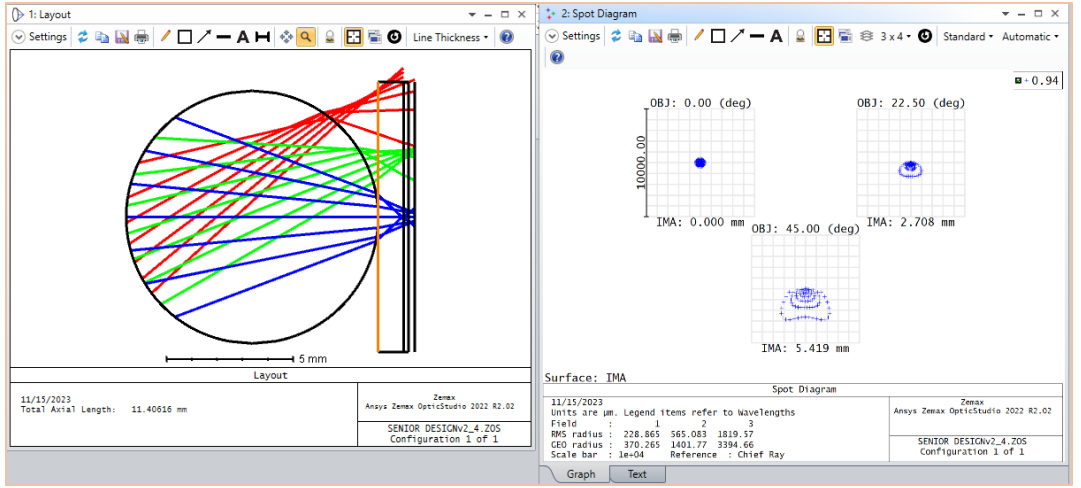
Photodiode Panel Design

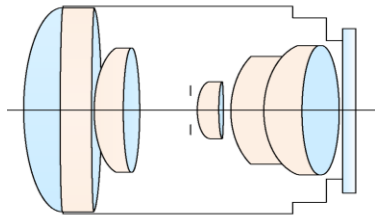


- Given angular field-of-view (AFOV), the maximum focal length (f) of the lens system used relates to the selected sensor's side length (H) by the equation **AFOV = 2*arctan(H2f)**
- Photodiode active area side length: 2.65 mm
- Lens system's maximum focal length using one photodiode: ~1.33 mm
  - Unachievable due to photodiode packaging and filter thickness
- **Solution: use a panel of three photodiodes**
- Practical active area dimensions: 10.65 mm * 2.65 mm
- Maximum acceptable focal length: ~5.325 mm
- Impact of blind spots due to photodiode packaging on performance should be minimal
  - It is impossible for the animal wearing the collar to pass the blind spots without passing the rest of the receiver

Receiver Lens System Selection and Design

Technology	Advantages	Disadvantages	Relative Price
Multi-Element Fisheye Lens System	•Widest potential field of view	•Costly and challenging to assemble •Not compact	High
Half-Ball and Ball Lenses	•Most compact •For ball lenses, omnidirectional optical axis	•Vulnerable to aberrations •Challenging to mount	Lower
Hemispherical Fresnel Lens Array	•Dome-shaped geometry conducive to use with sensors •Extremely cost-effective (for mid-infrared applications)	•Challenging to simulate •Unknown commercial availability for near-infrared applications	Lowest, for mid-infrared applications Unknown for near-infrared applications





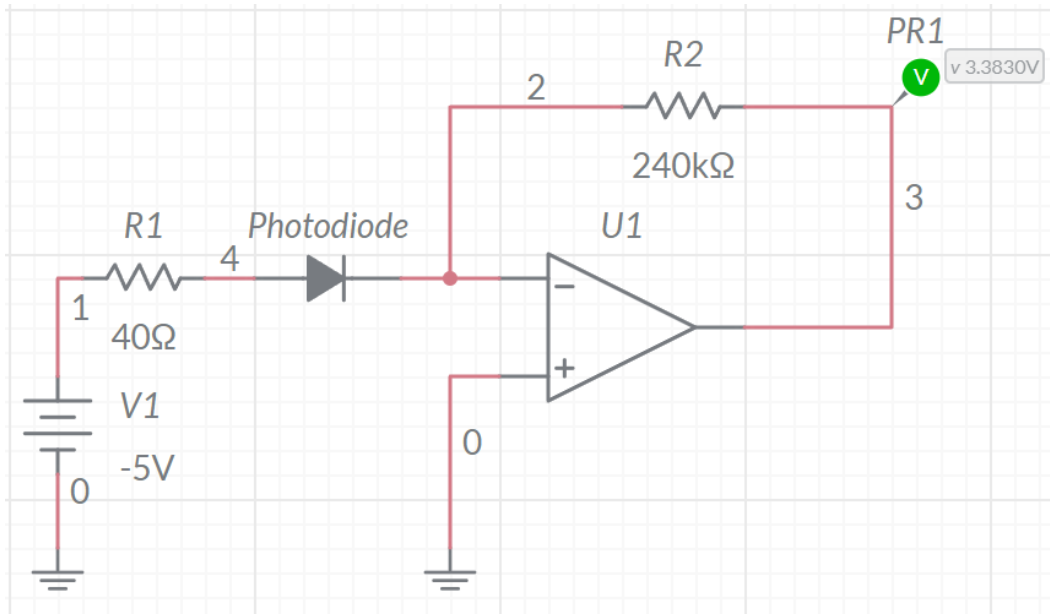
Multi-Element Fisheye Lens System

Half-Ball and Ball Lens

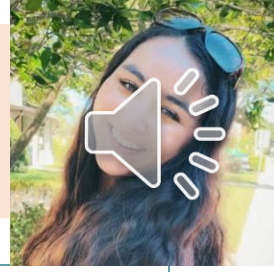
Hemispherical Fresnel Lens Array

Indoor Location Beacon Electrical Design

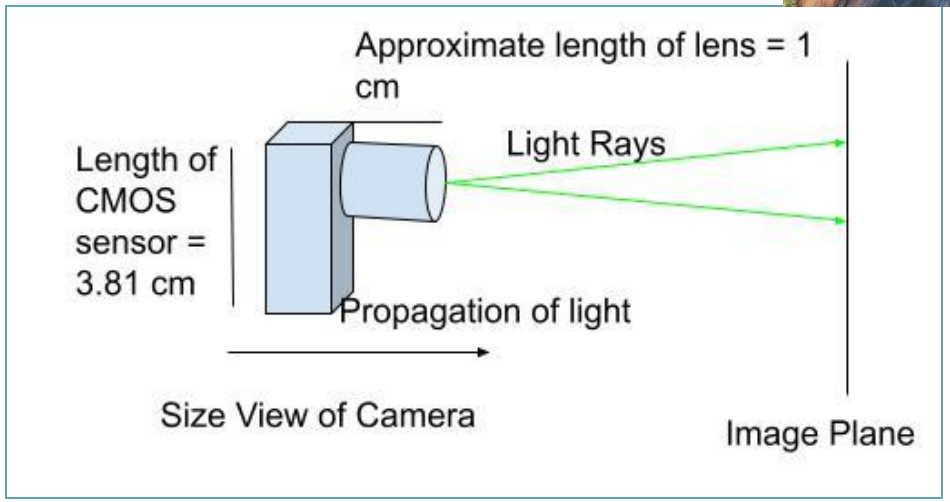
- Operational amplifier utilized to amplify the current generated by the photodiode.
- Outputted voltage connected to the analog to digital converter of the ESP32 microcontroller.
- Analog to digital converter reads the voltage output and provides a corresponding number

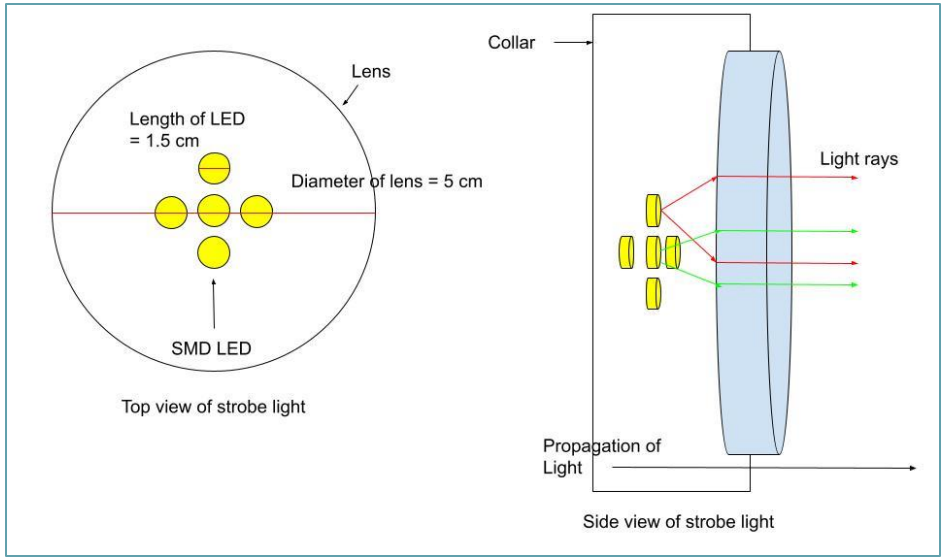


Predator Identification and Defense systems

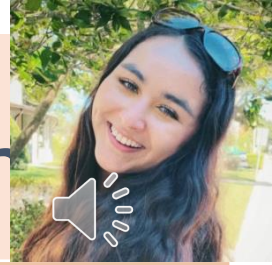


- Overall Design:
  - This system contains a strobe light and camera system
  - The identification part of the system will contain two cameras located on the front and back of the collar
    - This system will contain two cameras with custom lens designs that allow up to 180 degrees field of view.
  - The defense part of the system will contain a strobe light
    - This system contains two sets of five LEDs with a collimating lens that can be manually activated through the corresponding application.
    - Supplementary function is easy pet location





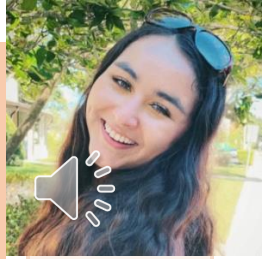
Predator Identification: CMOS Sensor Selection



Component	Required Voltage	Resolution	Shutter Type	Pixels	Dimensions	Price
Mega 5MP SPI Camera Module	3.3V	5 MP	Rolling	2592 x 1944	33mm x 33mm x 17mm	$34.99
Arducam for Raspberry Pi Camera	Variable	8 MP	Rolling	4608 x 2592	25mm x 24mm	$22.99
Arducam 64MP Camera Module for Raspberry Pi	Variable	64 MP	Rolling	9152 x 6944	25mm x 24mm	$59.99
OV5640 Camera Board	3.3V	5 MP	Rolling	2592 x 1944	35.70mm x 23.90mm	$25.99

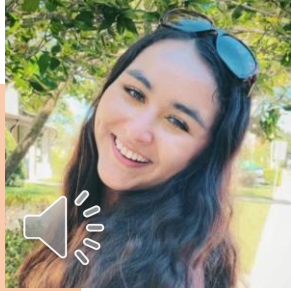
Types of CMOS sensors	Advantages	Disadvantages
Basic CMOS Sensor	Good image quality Uses less current and voltage	Image quality not as good as other CMOS sensors
Backside Illuminated CMOS sensor	Better for image noise Sharper and clearer image	Not as good for wide FOV
Stacked CMOS Sensor	Better space efficiency in sensor based on design Improved image quality	Produced for high end photography resulting in much higher producing

Predator Identification: Lens Design



Lens design	Advantages	Disadvantages
Fisheye Lens Design	Very Wide FOV Good Resolution	Fisheye distortion of image
Zoom Lens Design	Wide Variety of focal length	Complicated and timely lens design
Wide Angle Lens	Wide FOV Minimal distortion	FOV somewhat limited compared to other lens designs

Predator Defense: Strobe light LED selection



Component	Wattage (W)	Voltage (V)	Brightness (Lumens)	Dimensions	Beam Angle (Degrees)
Through Hole LEDs	0.192	3.2	11	37.36 mm	360°
SMD LEDs	1	3.6	110	15 mm	120°
Bicolor LEDs	0.066	3.3	40 - 65	2.5mm x 1mm x 0.7mm	130°
High Power LEDs	1	3.6	100	20mm x 8mm x 6.6mm	140°

Predator Defense: Strobe light lens selection

Glass	Wavelength Range	Refractive Index	Abbe Num.	Available Focal Lengths	Price
N-BK7 (Uncoated)	350nm - 2.0µm	1.515 at 633nm	64.17	10mm - 1.0m	$24.92
UV Fused Silica (Uncoated)	185nm - 8.0µm	1.460	67.82	10mm - 1000nm	$110.36
CaF_2 (Uncoated)	0.18µm - 8.0µm	1.428	94.99	15mm - 200mm	$208.47
ZnSe	7µm - 12µm	2.403 at 10.6µm	20 - 1000	15mm - 200mm	$342.54

Software Design

Onboard Software

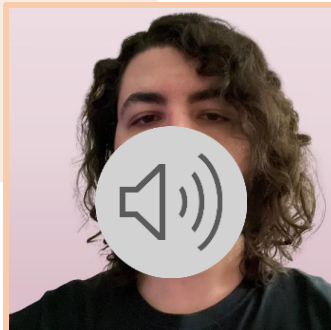
- Predator Detection
- GPS Tracking
- Sensor Storage

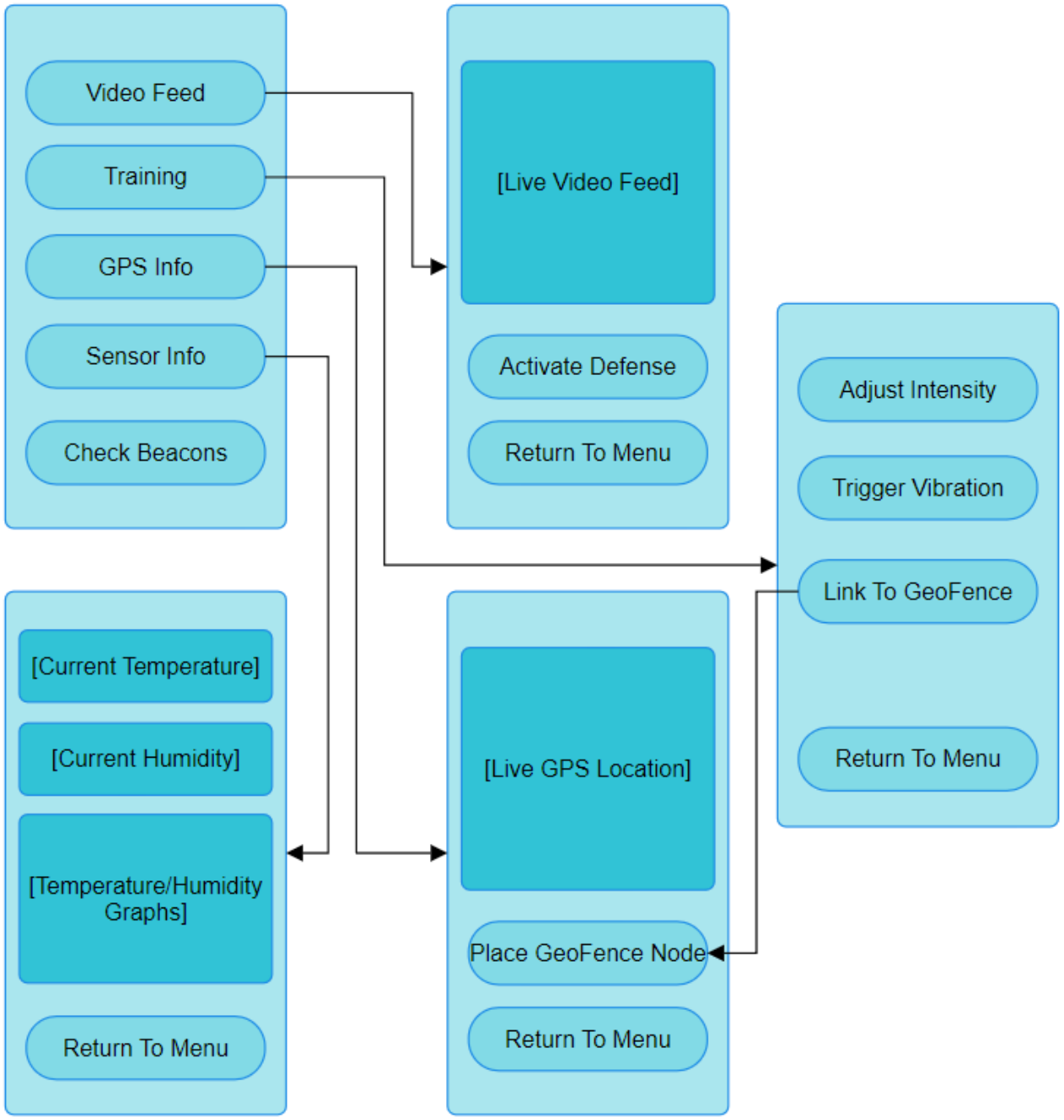
GUI Application

- Video Feed/Defense Activation
- GPS Location and Geofencing
- Sensor Information
- Training Functions
- Beacon Information

Auxiliary Beacons

- Live Data




Video Feed
Training
GPS Info
Sensor Info
Check Beacons
[Live Video Feed]
Activate Defense
Return To Menu
Adjust Intensity
Trigger Vibration
Link To GeoFence
Return To Menu
[Current Temperature]
[Current Humidity]
[Temperature/Humidity Graphs]
Return To Menu
[Live GPS Location]
Place GeoFence Node
Return To Menu

PCB Design

Software: Eagle 9.6.0

Constraints:

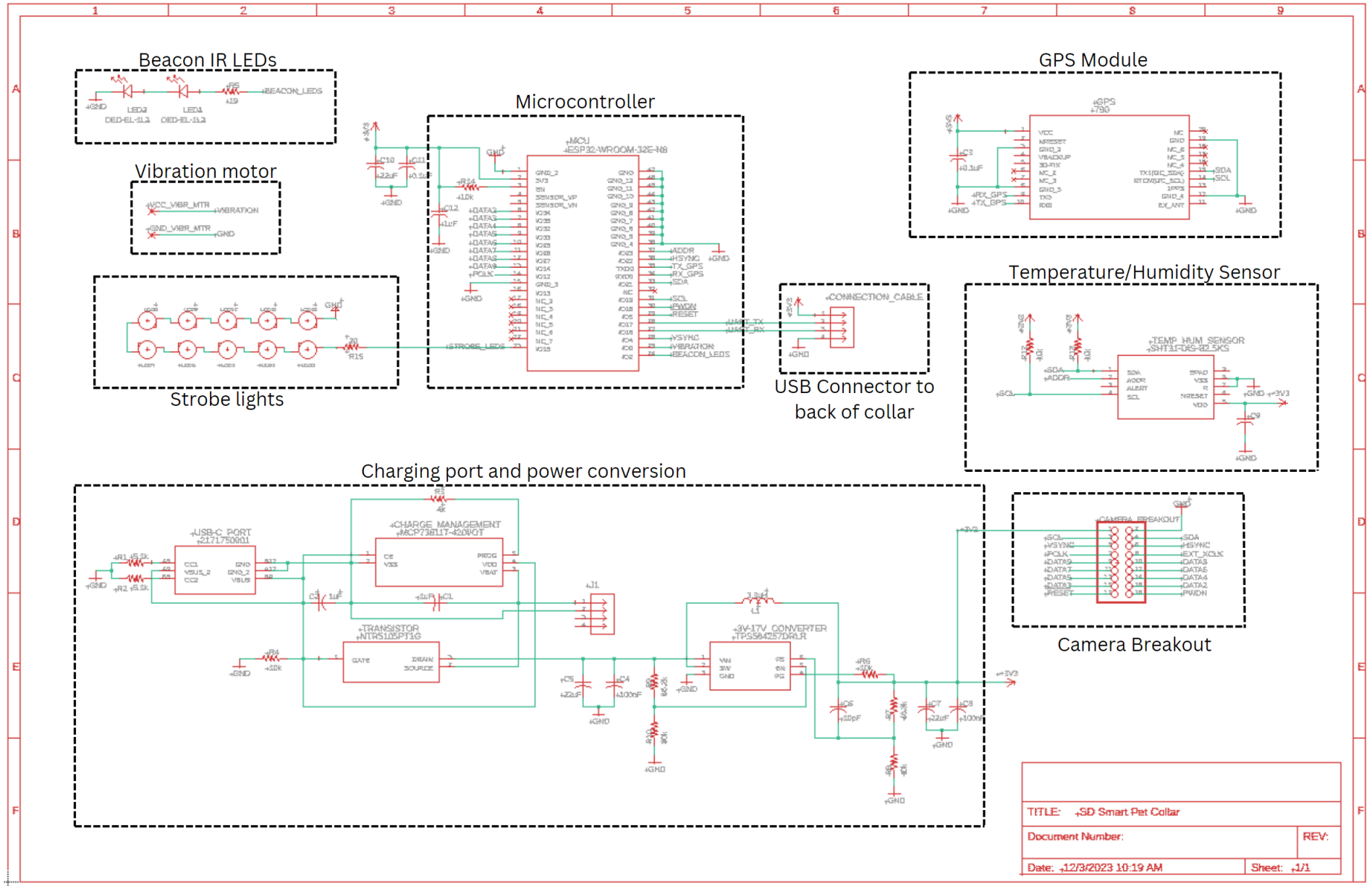
- Size
- Orientation of ports
- Spacing

Vendor: PCBWay

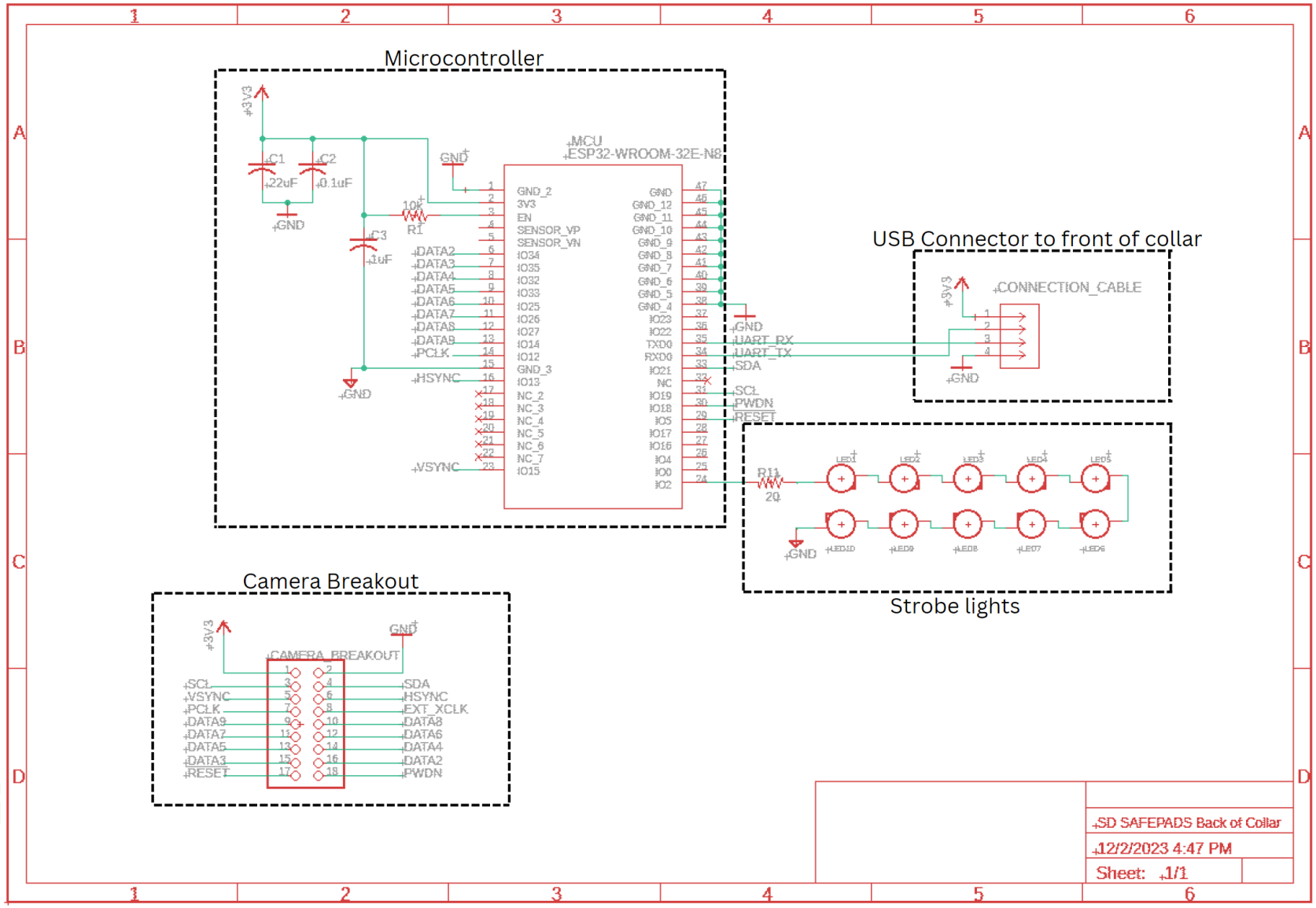
Constraints:

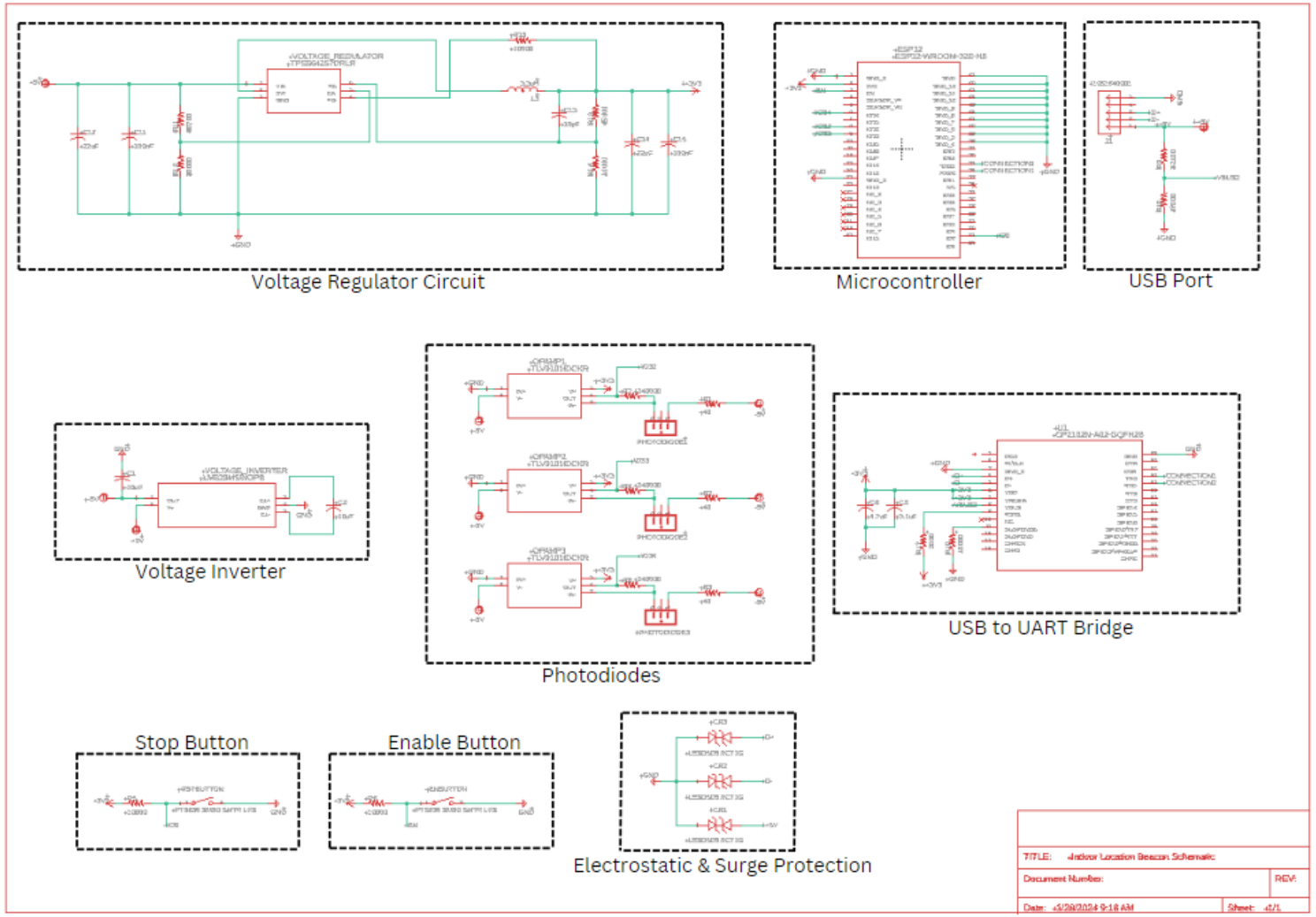
- Shipping time
- Price

Front of Collar Electrical Schematic



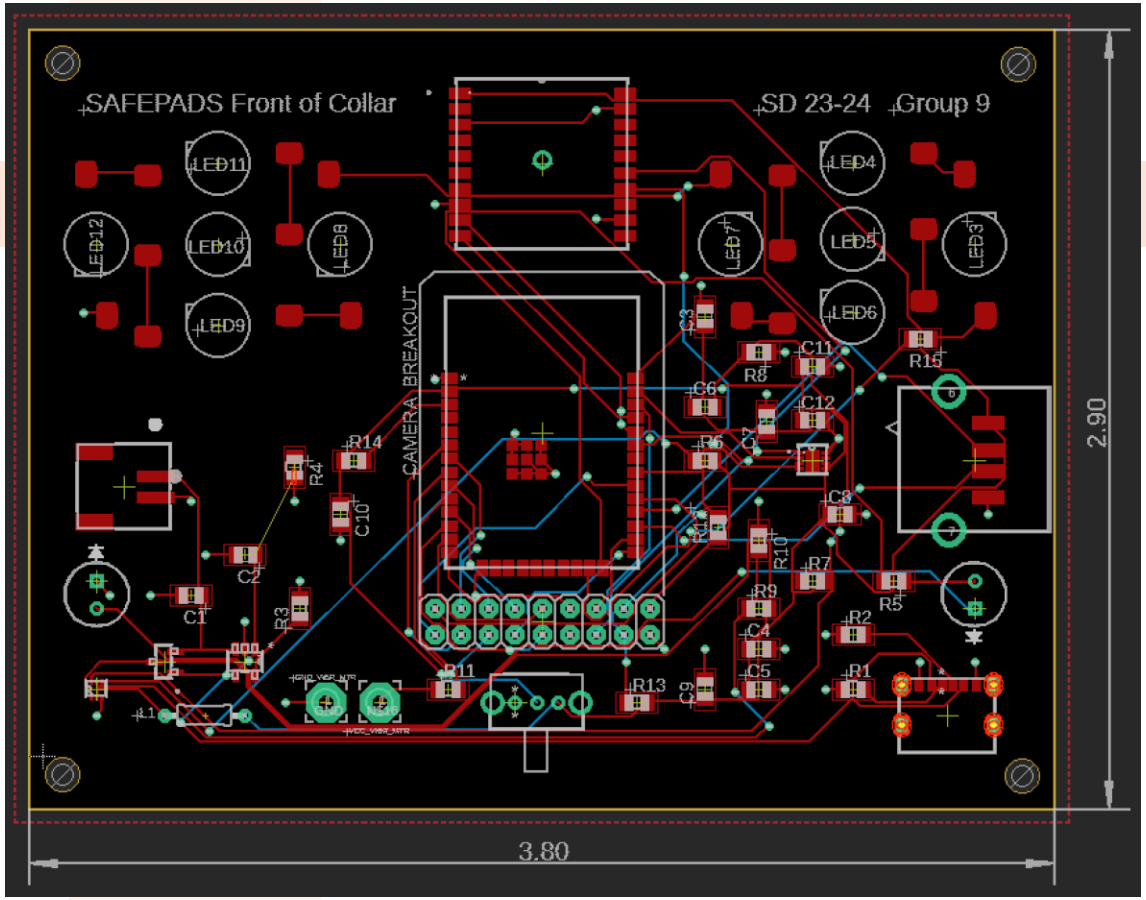
Back of Collar Electrical Schematic

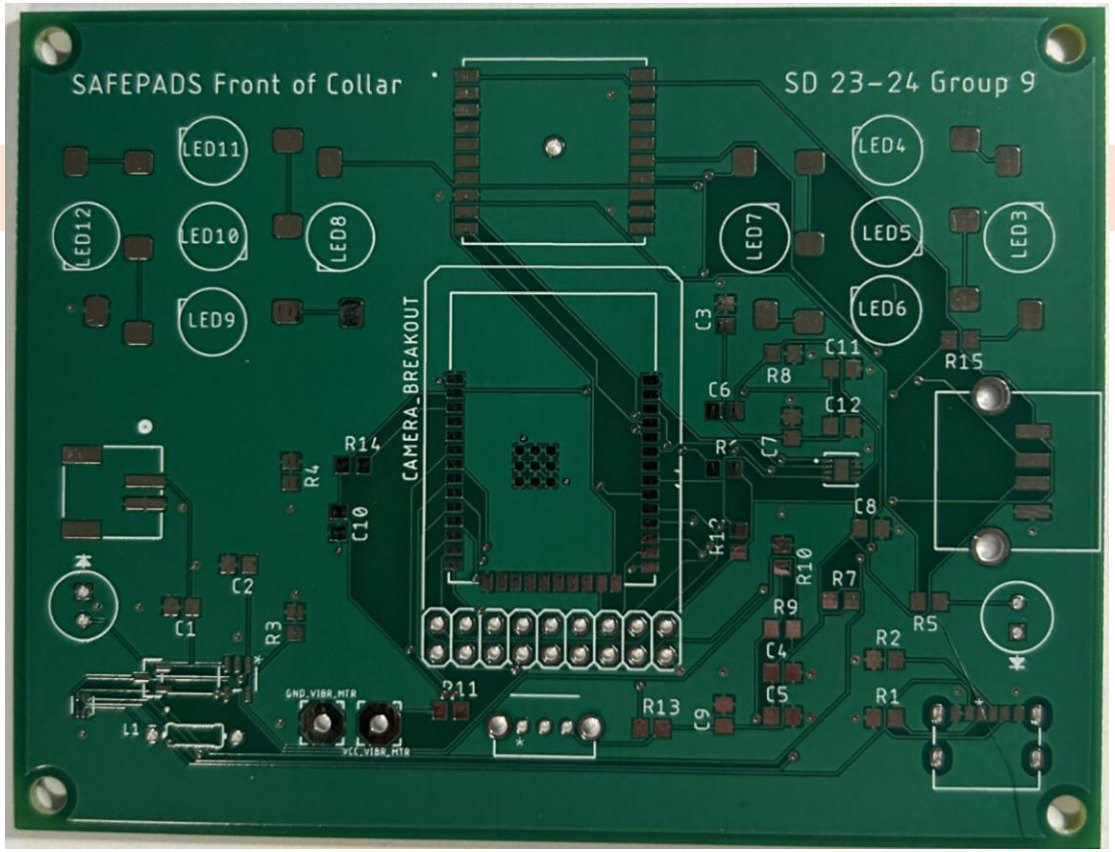




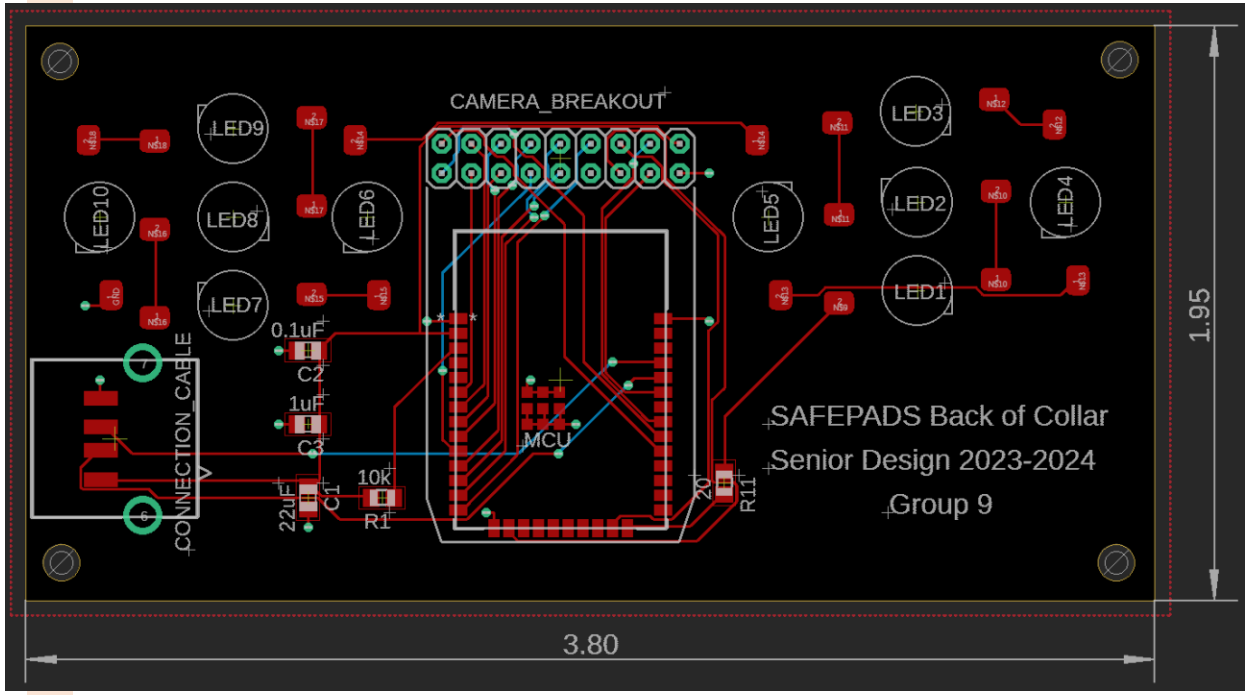
Indoor Location Beacon Schematic

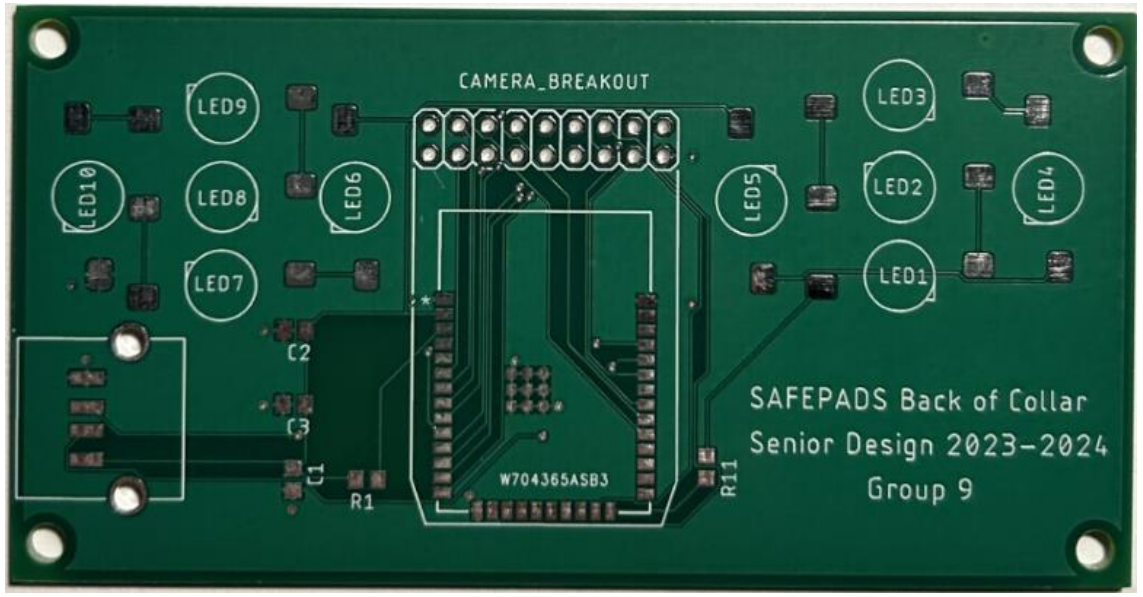
Front of Collar Board



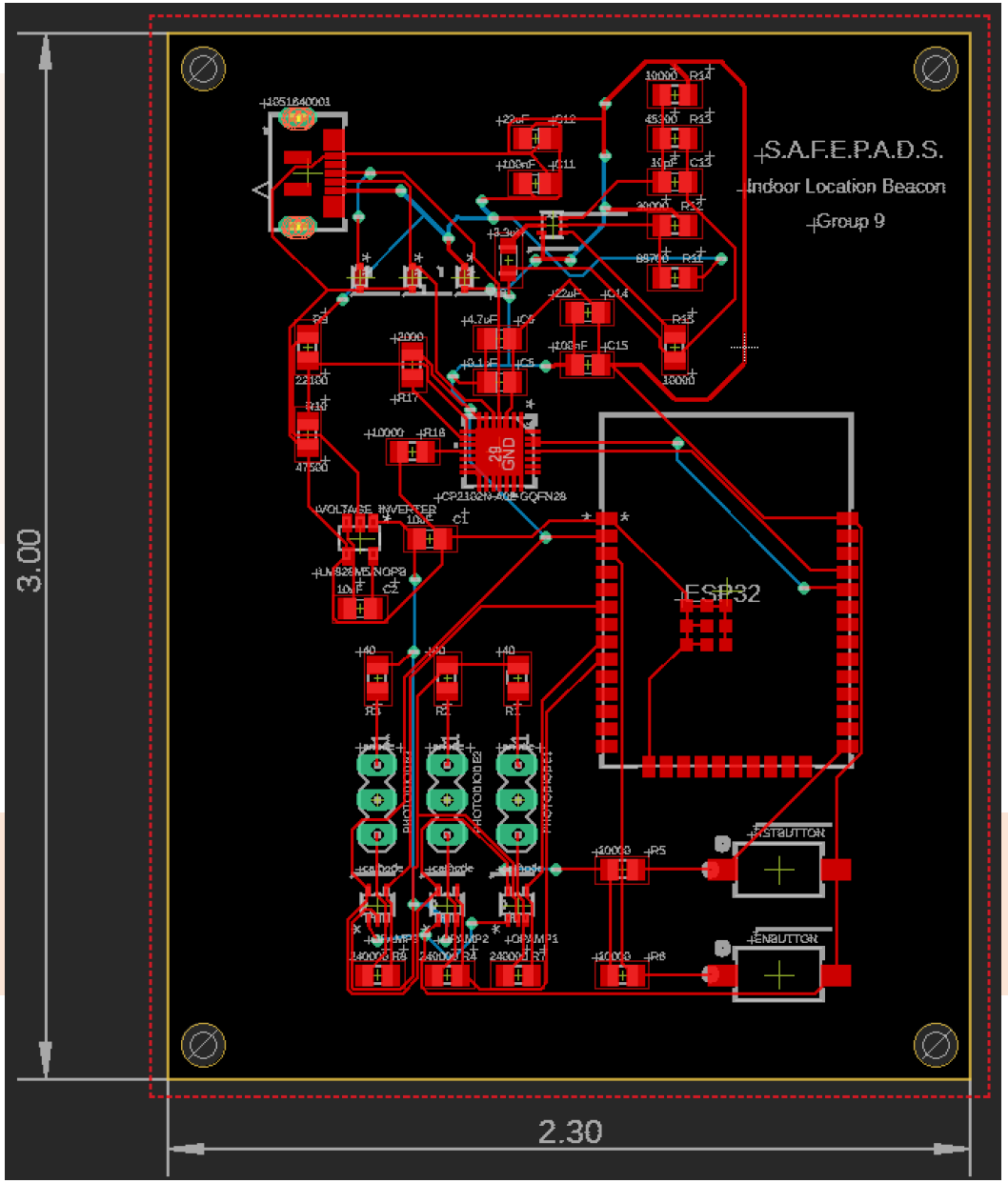


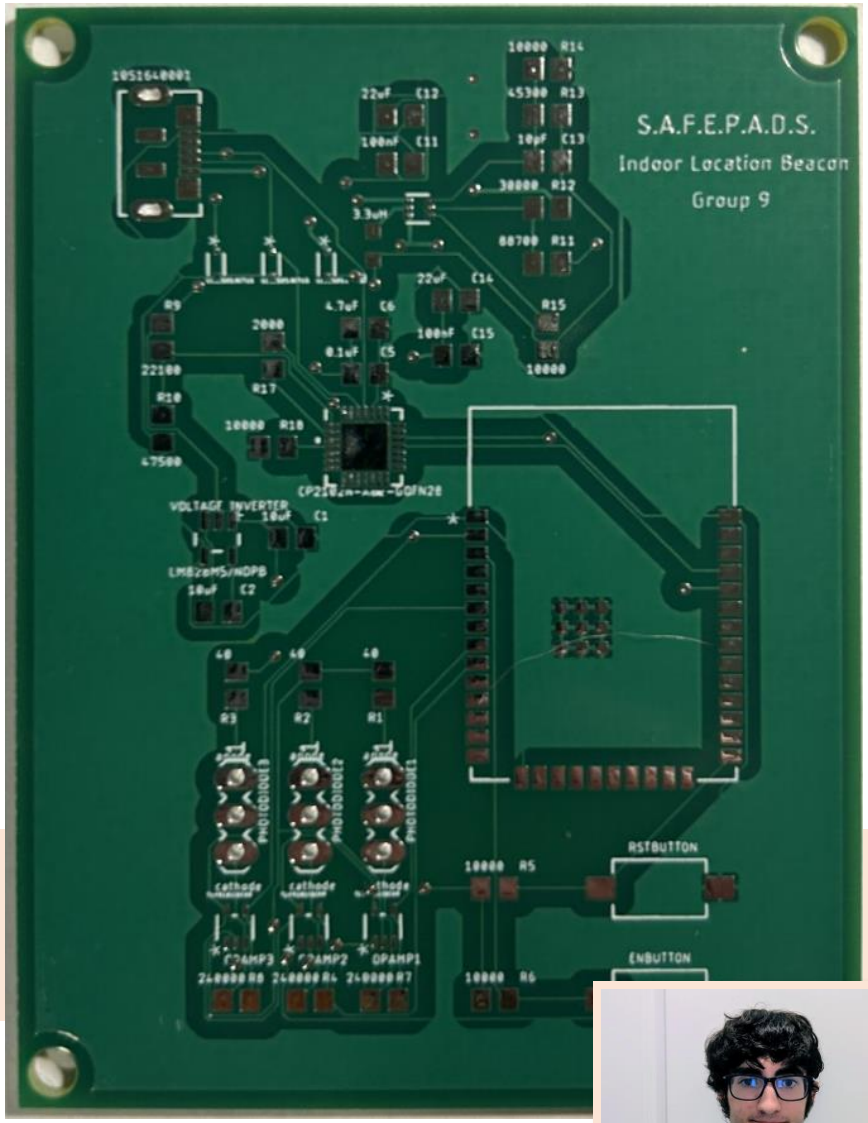
Back of Collar Board





Indoor Location Beacon Board

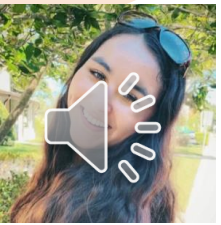




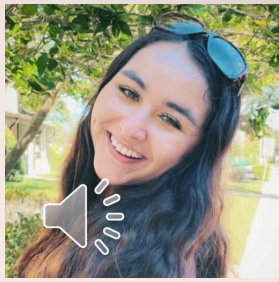
Budget

Total Sponsorship	$1000

Item Description	Vendor	Quantity	Price per Unit	Price
ESP32 WROOM Microcontroller	Amazon	10	$5.60	$55.98
PA1616S GPS Module	Adafruit	1	$24.95	$24.95
Adafruit Vibration Motor 1201	Digikey	2	$1.95	$3.90
OED-EL-1L1 LEDs	Mouser	10	$0.43	$4.30
SFH 2200 Photodiodes	Mouser	10	$1.39	$13.90
SCHOTT RG850 Filter	Edmund Optics	1	$32.00	$32.00
45-077 Lens	Edmund Optics	2	$26.00	$52.00
10 mm Ball Lens	MSE Supplies	1	$16.20	$16.20
SHT31-DIS-B Temp/Humidity Sensor	Digikey	4	$5.42	$21.68
PRT-13851 Lithium-Ion Battery	Amazon	2	$5.50	$11.99
OV5640 Camera Board	Amazon	4	$25.99	$103.96
Wide Angle Lens	Amazon	2	$45	$45
SMD LEDs	Amazon	10	$1.72	$1.72
Collimating Lens	Thorlabs	1	$24.92	$24.92
PCB v.1	PCBWay	10 (each)	$5	$136.83
PCB v.2	PCBWay	5 (each)	$5	$74.45
Project Sub-Total				$623.78



Work Distribution



Task	Primary Person	Secondary Person
Microcontroller Comparison and Testing	Sara Wijas	Austin Fugate
Temperature and Humidity Sensor Comparison and Testing	Austin Fugate	Sara Wijas
Global Positioning System (GPS) Comparison and Testing	Austin Fugate	Sara Wijas
Power Supply Design and Testing	Austin Fugate	Sara Wijas
Indoor Location and Fencing System Optical Design	Rana Scherer	Nadia Khan
Indoor Location and Fencing System Testing	Rana Scherer	Nadia Khan
Strobe Light Design and Testing	Nadia Khan	Rana Scherer
Wide FOV Camera Sensor Comparison	Nadia Khan	Rana Scherer
Wide FOV Camera Optical Design	Nadia Khan	Rana Scherer
Wide FOV Camera Testing	Nadia Khan	Jesus Pagan Vela
Vibration Motor Comparison and Testing	Sara Wijas	Austin Fugate
Front of Collar PCB Design	Sara Wijas	Austin Fugate
Back of Collar PCB Design	Sara Wijas	Austin Fugate
Indoor Location and Fencing PCB Design	Austin Fugate	Sara Wijas
GUI Design	Jesus Pagan Vela	Sara Wijas
Software Design	Jesus Pagan Vela	Austin Fugate
Image Processing Testing	Jesus Pagan Vela	Austin Fugate

Progress

- Tested charging circuit and verified it works
- Beacon system has demonstrated the ability to provide a readable output to the ESP32
- GPS has shown the ability to implement geofencing and is currently being refined
- Temperature and humidity sensor providing accurate outputs

Thank You!

Questions?