P.A.W.S.

Protected **A**ccess for **W**hiskered **S**ubjects: AI-Assisted Litter Box System

Group 9:

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Meet The Team

Luana Capel

Photonic Science and Engineering

Kinza Rashid

Computer Engineering

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Electrical Engineering

Christian Williams

Computer Engineering

Background and Motivation

- **Species-Specific Design**
  - Litter boxes are designed with cats' behavioral and hygiene needs in mind
- **Health and Hygiene**
  - Dogs accessing the litter box can affect both pet and human health
- **Preventing Risks**
  Restricting access minimizes the potential transmission of parasites and diseases

✓ We are aiming to improve pet health, enforce proper behavioral practices, and create a cleaner, safer living environment by developing a system that allows only cats into the litter box

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Goals

1. **Physical enclosure with easy human access**
   - Wooden enclosure that can seamlessly blend into everyday furniture

2. **Motorized door with safety measures**
   - Plexiglass door with sensors to prevent injury

3. **Object detection**
   - AI powered real-time image processing for animal identification

4. **Live feedback for the user**
   - Mobile app to notify owner of litter box activity via notification

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Objectives

1. **Physical enclosure with easy human access**
   - Build a wooden box with top mount hinge door for quick and easy access to litter box
2. **Motorized door with safety measures**
   - Plexiglass along a railing system powered by stepper motor, with infrared sensor to prevent door closing on the cat
3. **Object identification**
   - Raspberry Pi camera module able to quickly identify a cat or dog in the frame with at least a 75% accuracy
4. **Live feedback for the user**
   - Mobile application will send push notifications when the door is opened, store pictures from the Pi camera, and keep an activity log

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Engineering Specifications

For Major Components

	Component	**Parameter**	Specification
Electrical	Power Supply	Support Max Delivery	Up to 96W
	Regulators	Voltage Regulation	Provide stable 3.3V and 5.2V
	Motor	Reliability	Operate without fail **90%** of the time
	Motor Driver	Current Handling Capacity	Support up to 2.5A
	PCB	Power Draw	Less than 55W
	Image Processor	Response Time	Delivers verdict of identifying cat within **3 seconds** image capturing
Optical	Proximity Sensor Lens	FOV	**60°**
		Focal Length	15-25 mm
	Infrared LED	Output Power	150 mW
		Peak Wavelength	940 nm
	Photodiode	Receiving Angle	40°
		Range	7-8 m

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System Engineering Requirements

Product Requirement	Requirement Specification
Object detection distance	~ 12-18 inches
Cat identification accuracy	≥ 75 %
FOV of IR imaging camera	≥ 75 °
Raspberry Pi response	≤ 3 seconds
Door open/close timing	≤ 8 seconds
Rail-system minimum linear velocity	≤ 1inch/second
Minimum weight detection for pressure pad	≥ 1 pound

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Physical Enclosure

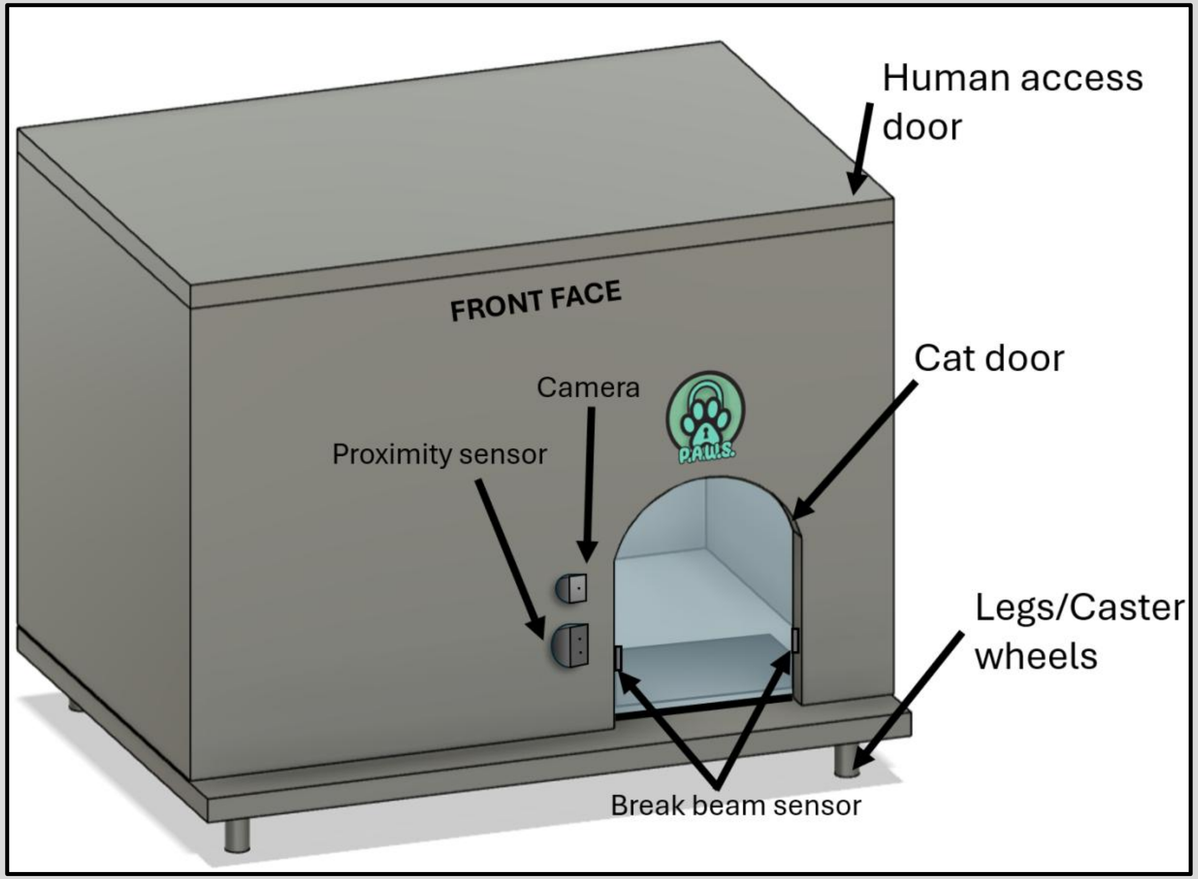

Fig 1. 3D model of physical enclosure

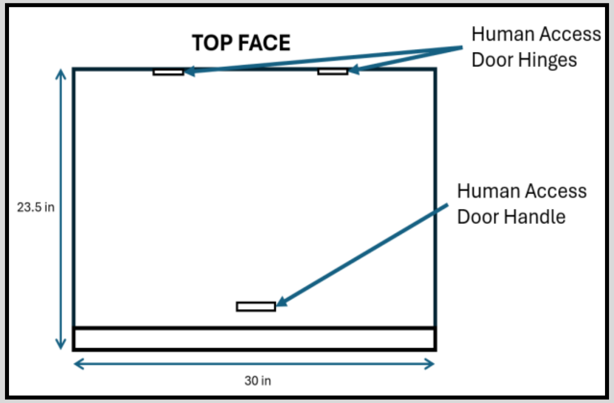

Fig 2. 2D view of outer top face of enclosure

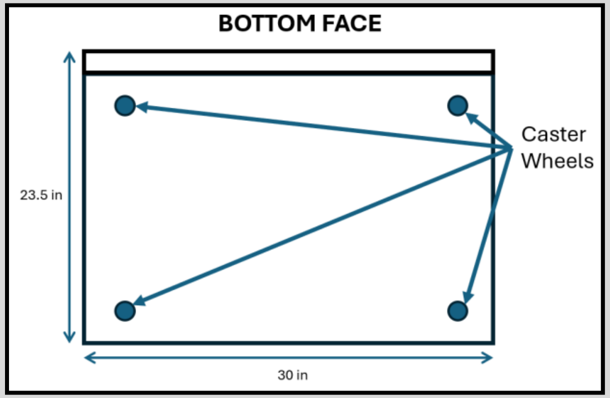

Fig 3. 2D view of outer bottom face of enclosure

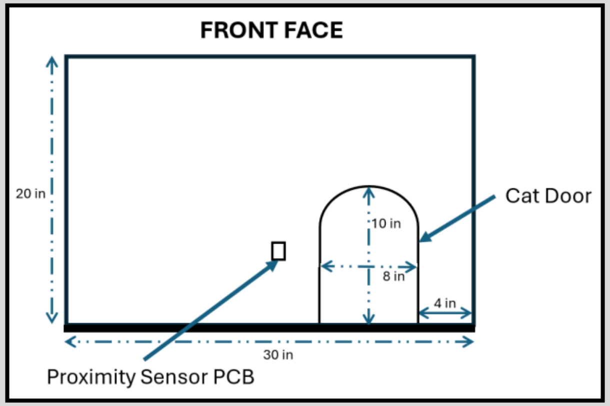

Fig 4. 2D view of outer front face of enclosure

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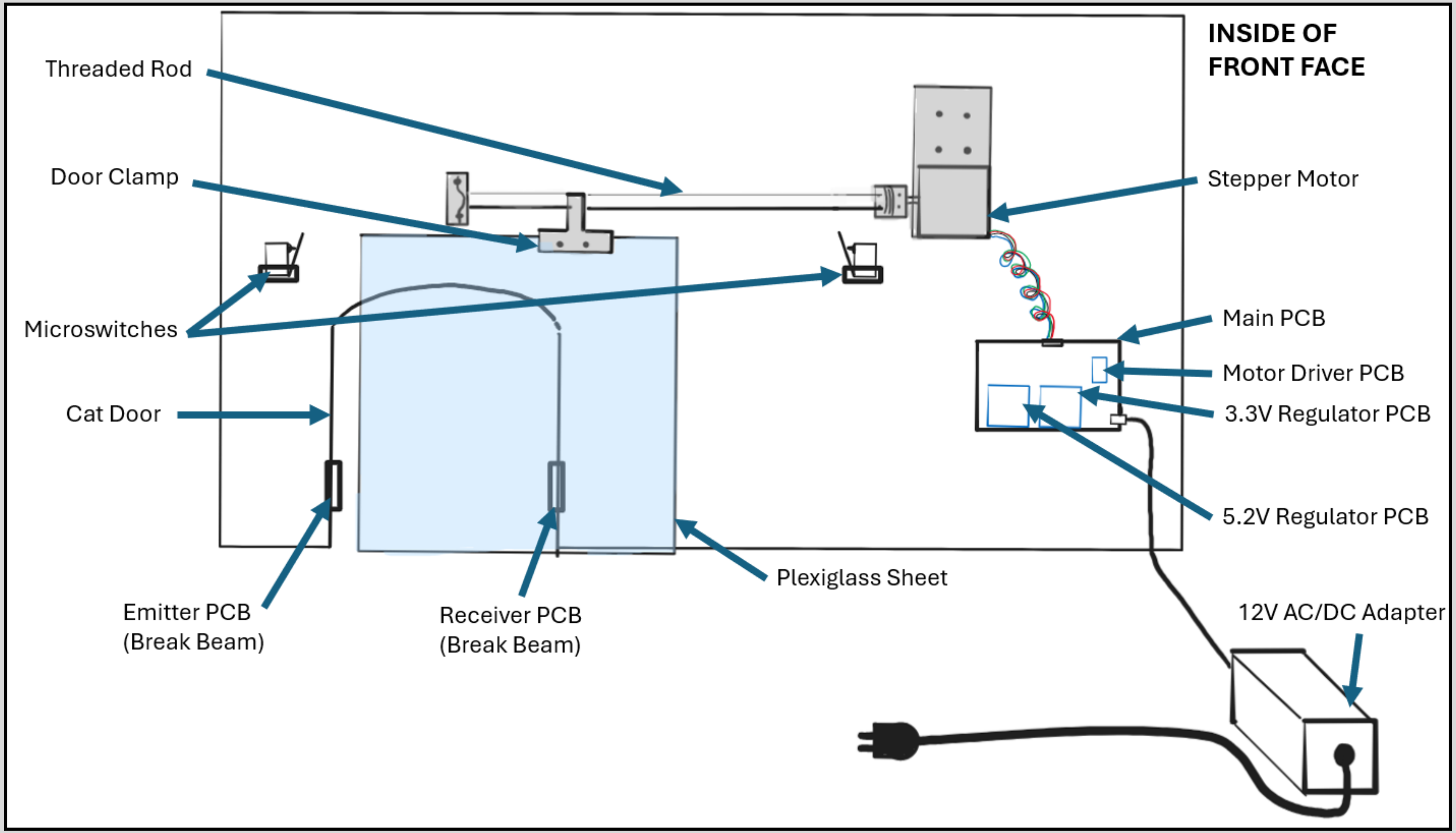
Physical Enclosure – Cont.



2D view of inner front face of enclosure

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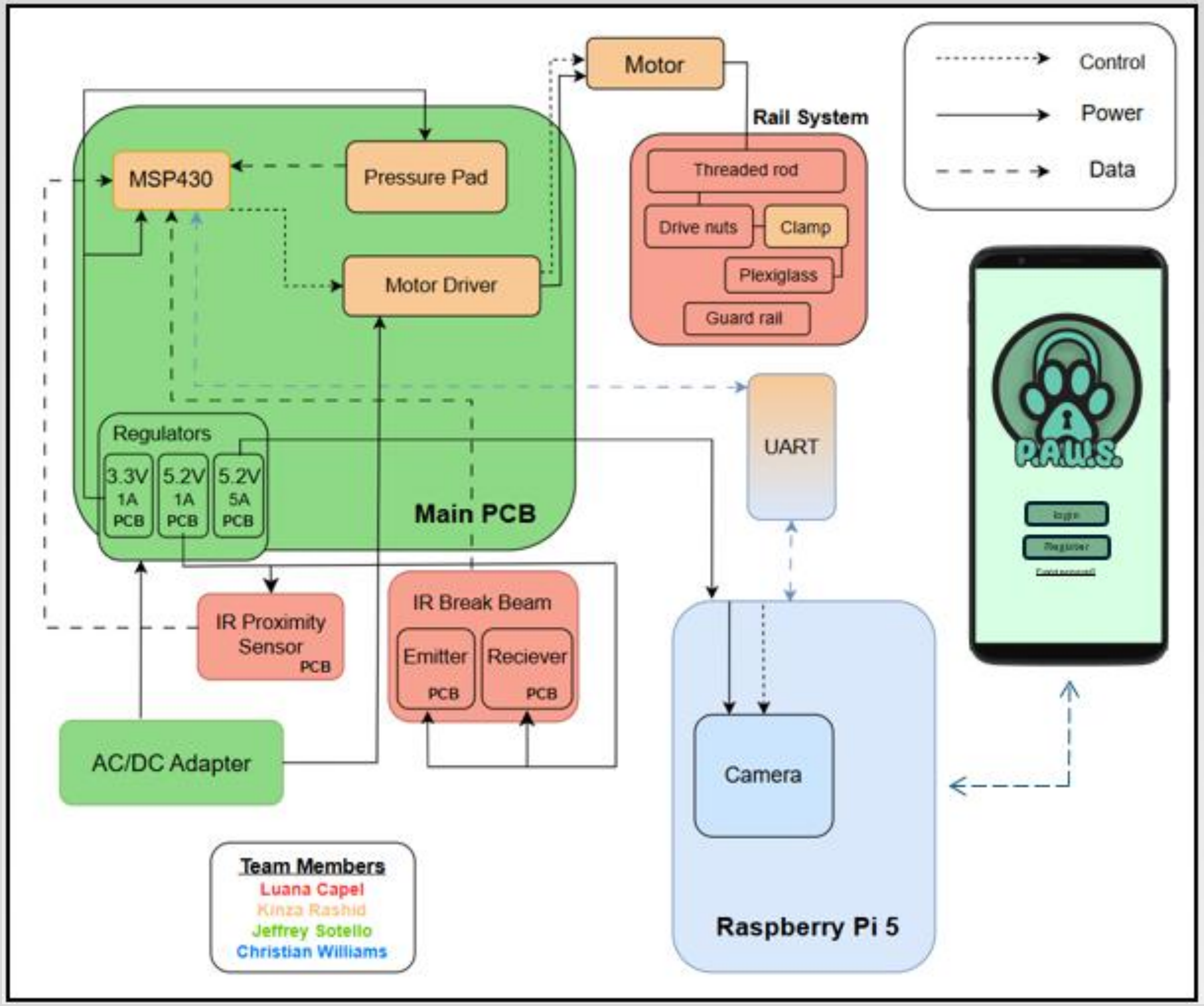
Hardware Block Diagram



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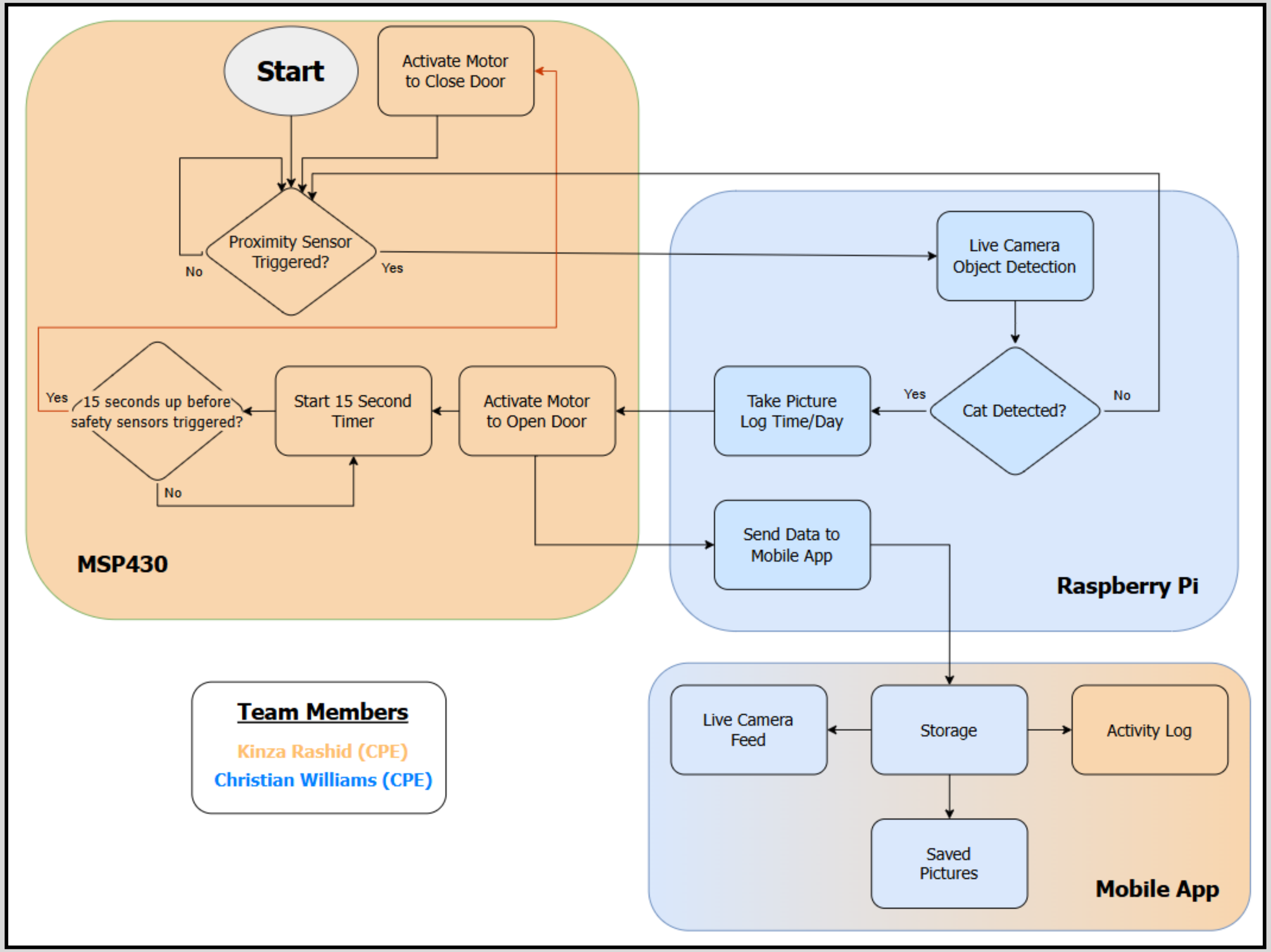
Software Block Diagram



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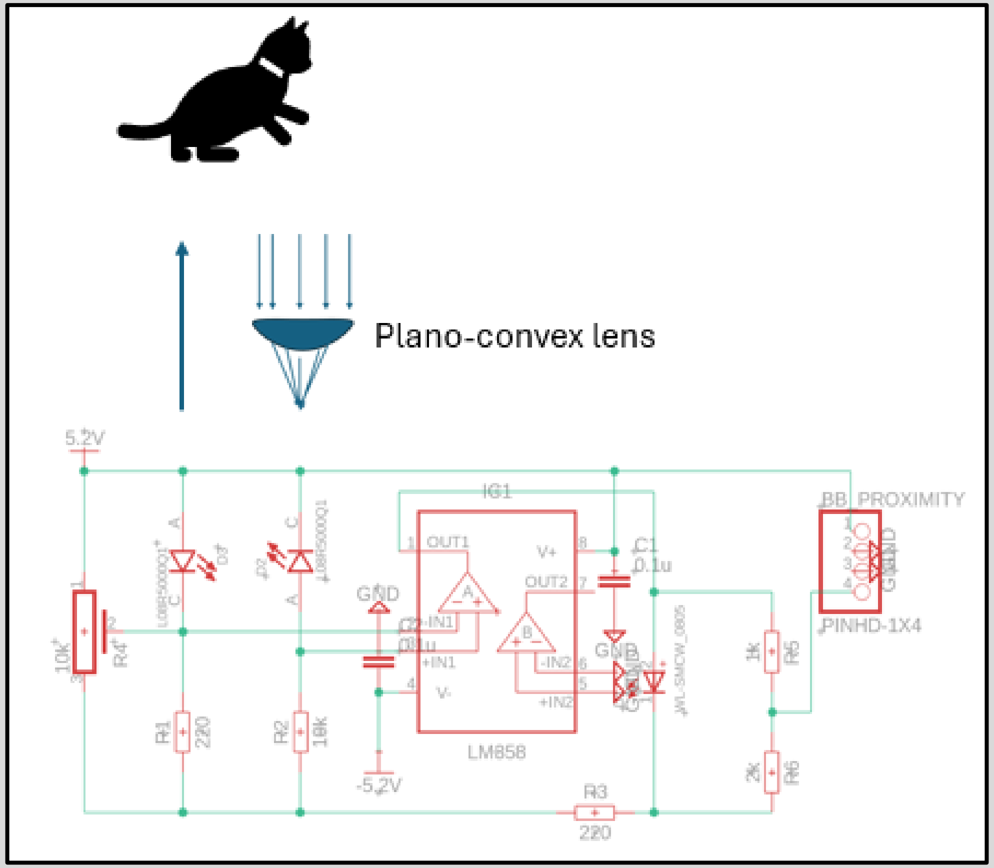
Proximity Sensor

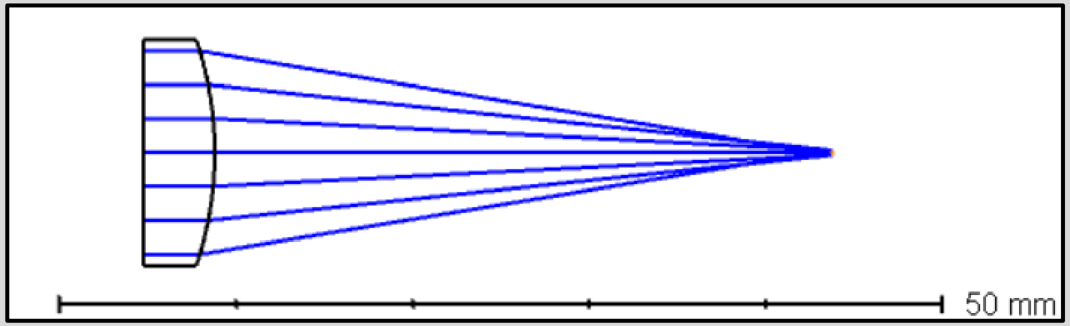


Overall Schematic of proximity sensor design

- FOV 60°
- Diameter = 25mm
- EFL = 21.6mm

$$EFL = \frac{d}{2 * \tan\frac{FOV}{2}}$$

	Surface Type		Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6
0	OBJECT	Standard		Infinity	Infinity			0.000	0.000	0.000	0.0...	0.000
1	STOP	Standard	lens fron	-12.9...	3.000	N-BK7		6.350	0.000	7.211	0.0...	-
2		Standard		Infinity	500.0...			7.211	0.000	7.211	0.0...	0.000
3	IMAGE	Standard		Infinity	-			149.305	0.000	149.305	0.0...	0.000



Lens Design on Zemax

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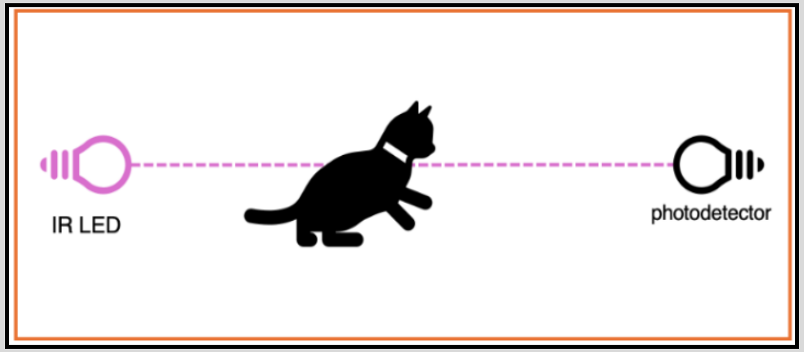
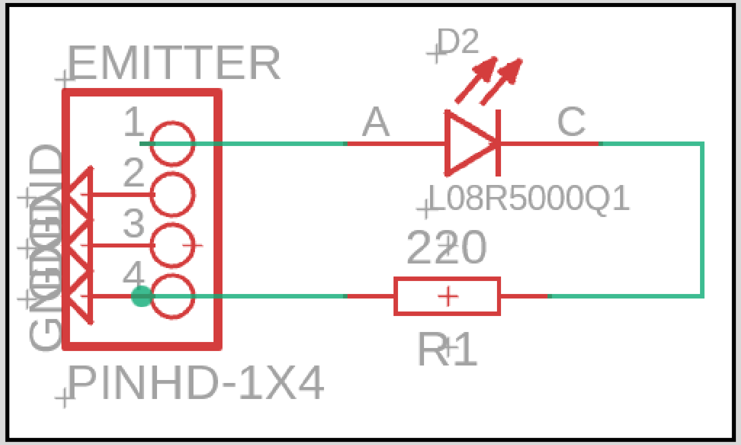
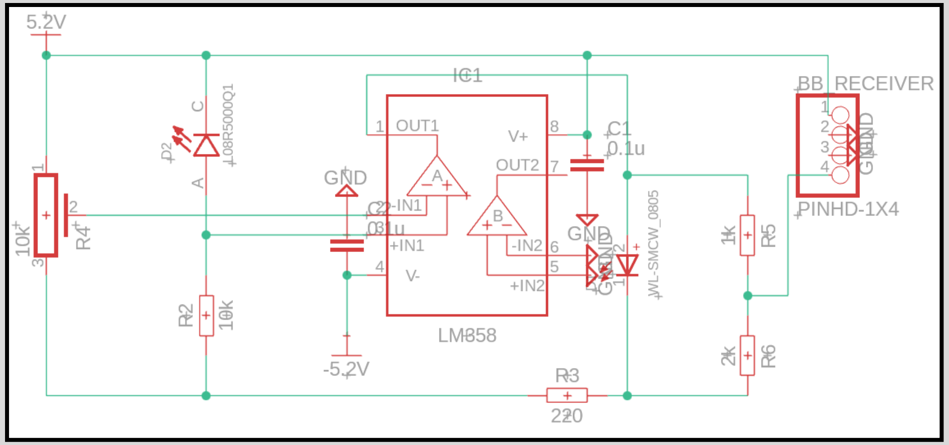
Break-beam Sensor





Emitter PCB Schematic



Receiver PCB Schematic

Overall Schematic of break-beam sensor design

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Pressure Pad Comparison and Selection

- Additional safety layer and door-opening mechanism

Feature	Velostat	Load Cell Weight Sensor
MCU Compatibility	All	Raspberry Pi and Arduino
MCU Interfacing	Directly to ADC pin	Separate ADC module (e.g. HX711) required
Resolution	Non-measurable	High weight-precision
Durability	Less	High
Construction	Higher initial setup time	Easy set up
Supply Voltage	User-defined	Dependent on weight capacity
Cost	$	$

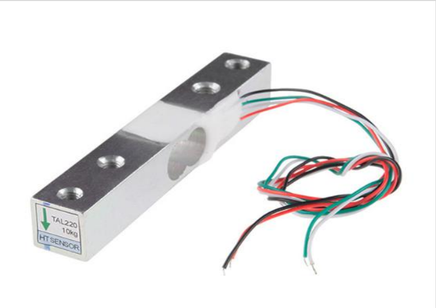

Fig 1. Load cell weight sensor

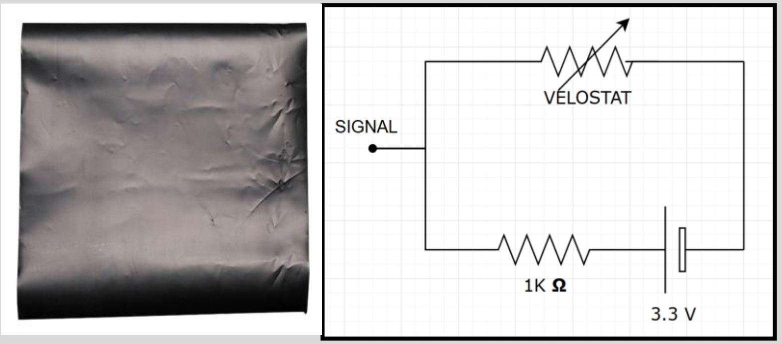

Fig 2. Velostat (left) and example of a velostat pressure sensor circuit

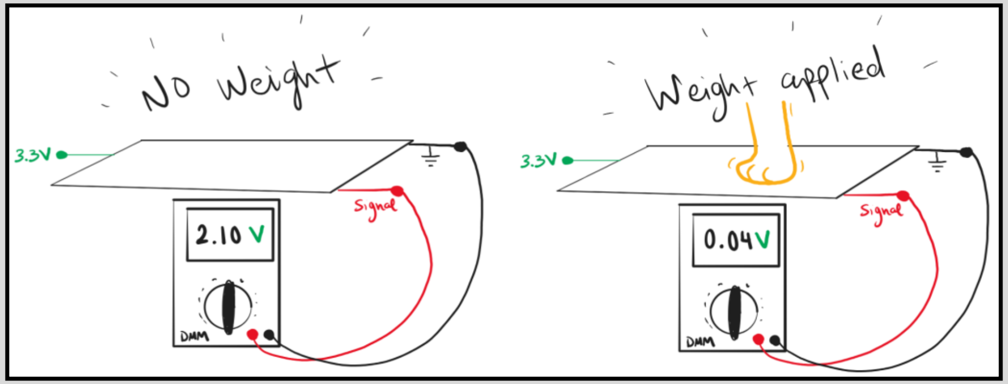

Fig 3. Velostat pad circuit voltage readings

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Rail System Comparison

Feature	Lead Screw	Belt Drive
Speed and Acceleration	Slower but consistent motion	High speed and acceleration
Load Capacity	Higher load capacity	Lower load capacity
Precision/Accuracy	High precision and repeatability	Lower precision due to belt stretch
Efficiency/Energy	Lower efficiency	High efficiency, low friction
Durability/Maintenance	Wear over time, may require lubrication	Belts wear over time, needing tensioning and/or replacement
Noise/Smoothness	Can be noisy if no dampening	Quieter, smoother operation
Input Torque Required	Low	High
Applications	CNC machines, 3D printers, high-precision positioning	Conveyor systems, robotic arms, pick-and-place
Cost	$	$$

Fig 1. Lead screw linear actuator

Fig 2. Belt drive linear actuator

Fig 3. 400-mm lead screw linear actuator to be used in P.A.W.S. rail system

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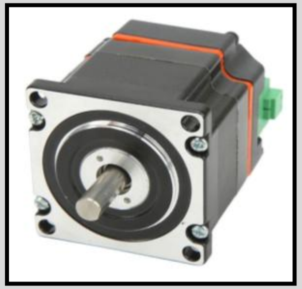
Motor Comparison

*Initial considerations (no longer in selection)

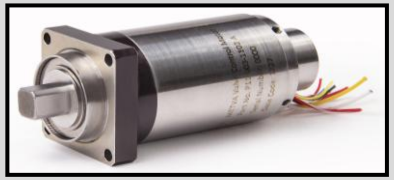
	Motor Type	Advantages	Disadvantages	Price
*AC	Induction	High efficiency at full load, suitable for high-power uses	Requires additional control for variable speed operation	$$
	Synchronous	High efficiency across speed range, precise speed control	High initial cost	$$$
DC	*Brushed	Simple control	Requires maintenance	$
	BLDC	High efficiency, low maintenance, good speed control	Higher cost than brushed	$$
	Servo	Precise position and speed control, high efficiency	Complex control	$
	Stepper	Precise position control, no feedback required	Lower efficiency, torque drops at high speed	$

Final Motor Options

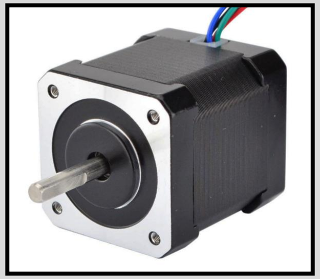
Servo



BLDC



Stepper



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Motor Selection

Stepper Motor

- Drives plexiglass sheet left/right horizontally to allow/block access through the cat door

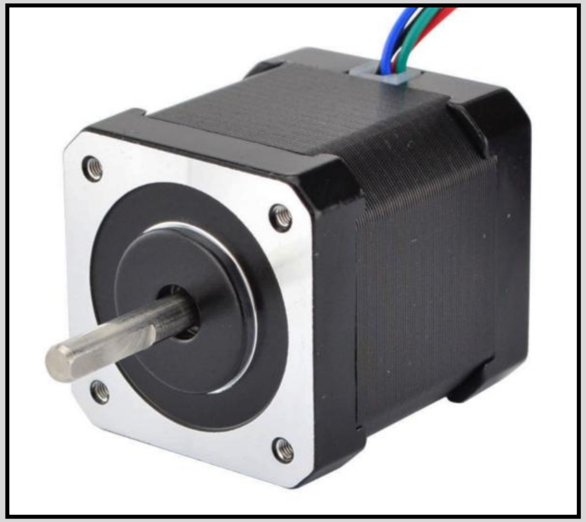

Fig 1. NEMA 17 stepper motor

Standard NEMA Model	NEMA 17	NEMA 17	NEMA 23	NEMA 23
Manufacturer Part Number	17HS19-2004S1	M42SH48-1684A	23HS30-2804S	23HS9430
Holding Torque	59 N-cm	59 N-cm	190 N-cm	210 N-cm
Rated Current/Phase	2.0A	1.68A	2.8A	3.0A
Phase Resistance	1.4Ω	1.65Ω	1.13Ω	0.75Ω
Phase Inductance	3.0mH ± 20% (1Khz)	2.8mH ± 20%	5.4mH ± 20%	4mH ± 20%
Driving Voltage	12V	12V-24V	3.2V	20V
Dimensions (L x W x H)	1.65" x 1.65" x 1.89"	1.65" x 1.65" x 1.85"	2.24" x 2.24" x 3.0"	3.19" x 1.85" x 2.21"
Price	$13.99	$15.99	$29.99	$30.00

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Microcontroller Comparison

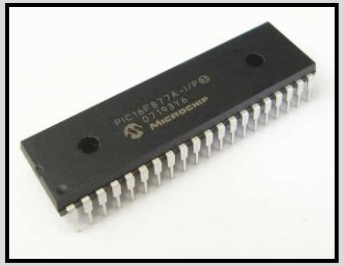
*Initial considerations (no longer in selection)

MCU	Advantages	Disadvantages	Price
*STM32	Powerful ARM-based	Complex development environment, steeper learning curve	$$
*ATmega328	Classic 8-bit, widely used	Limited processing power and memory	$$
ESP32	Built-in WiFi/Bluetooth, powerful dual-core processor, rich peripherals	Higher power consumption, overkill for simple projects	$
PIC	Wide variety of models, good documentation, reliable	Proprietary toolchain, less modern development environment	$
MSP430	Ultra-low power consumption, simple architecture, mature development tools	Limited processing power, smaller community compared to others	$

Final MCU Options

ESP32

PIC Family



MSP430

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Microcontroller Selection

MSP430 Responsibilities

- Motor Control
- Proximity Sensor
- Break Beam Sensor
- Pressure Pad Sensor
- UART Communication

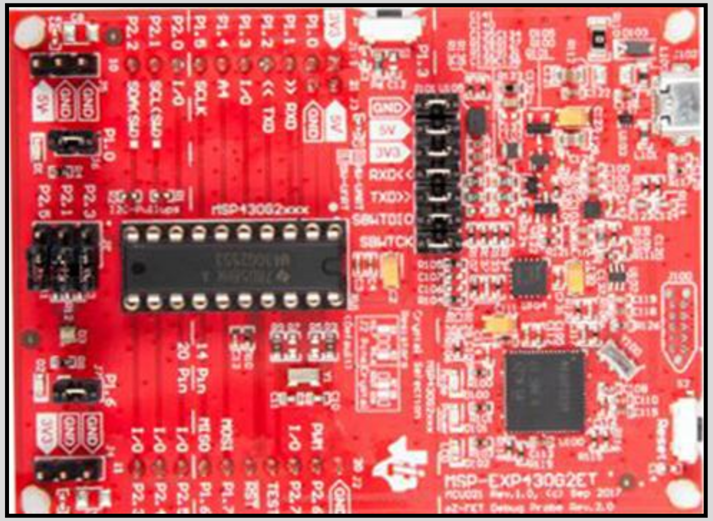

Fig 1. MSP430G2553 LaunchPad™ Development Kit

Details	MSP430G2553	MSP430FR6989
Nonvolatile memory (kByte)	16	128
RAM (kByte)	0.5	2
ADC type	10-bit SAR	12-bit SAR
Number of ADC channels	8	16
Number of GPIOs	24	83
Features	Real-time clock, Spy-bi-wire, Watchdog timer	Advanced sensing, DMA, LCD, Real-time clock, Scan interface
UART	1	2
Timers - 16-bit	2	5

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Machine Learning Computation Comparison

Feature	Single-Board Computer	Cloud Computing
Latency	Real-time processing	Network dependent
Networking	Works offline	Requires internet
Security	Data computed locally	Data computed online
Performance	Limited to hardware specs	Scalable as needed
Setup	Requires physical setup	No physical setup
Maintenance	Hardware upkeep, may need replacing overtime	Managed by cloud provider
Cost	One-time medium cost	Recurring small costs

Raspberry Pi

Google colab

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Single-Board Computer Comparison

Component	Raspberry Pi 4	Raspberry Pi 5	Coral Dev Board Mini	BeagleBone Black
CPU	Quad-core ARM Coretex-A72	Quad-core ARM Coretex-A76	Quad-core ARM Coretex-A35	ARM Coretex-A8
CPU Clock Frequency	1.8 GHz	2.4 GHz	1.5 GHz	1 GHz
GPU	VideoCore VI	VideoCore VII	PowerVR GE8300	SGX530 3D Graphics Engine
RAM	1GB/2GB/4GB/8 GB LPDDR4	2GB/4GB/8GB LPDDR4x	2GB LPDDR3	512MB DDR3
RAM Clock Speed	3200 MHz	4267 MHz	1600 MHz	800 MHz
Storage	microSD, USB 2.0/3.0	microSD, USB 2.0/3.0	8GB eMMC, microSD	4GB eMMC, microSD
Networking	GB Ethernet, Wi-Fi, Bluetooth	GB Ethernet, Wi-Fi, Bluetooth	Wi-Fi, Bluetooth	Ethernet
Power Consumption	5V, 3A	5V, 5A	3.3V, 3A	5V, 2A
Approx. Cost	\$35.00 - \$75.00	\$50.00 - \$80.00	\$99.99	\$53.62

Important factors to consider:

- Budget
- Availability
- Processing capabilities
- Networking for mobile app integration
- Ease of setup and use

Raspberry Pi 5

Coral Dev Board Mini

BeagleBone Black

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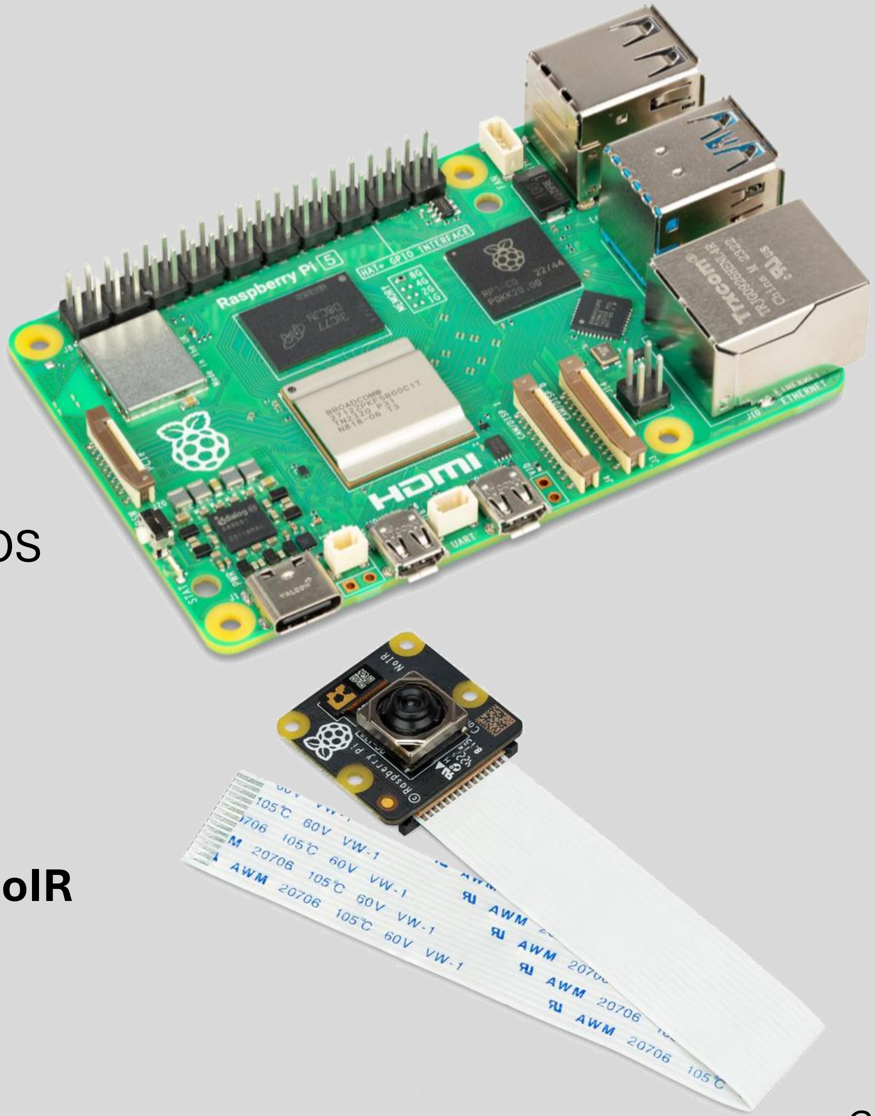
Single-Board Computer Selection

To handle the P.A.W.S. project's machine learning tasks, we chose the **Raspberry Pi 5 4GB**

- Affordable at $60 for the 4GB version
- Widely available at most major retailers
- Powerful enough to handle object detection and classification machine learning tasks
- Easy setup, just insert a microSD card with Raspberry Pi OS installed
- Wi-Fi and Bluetooth capabilities for communicating with mobile app
- UART GPIO pins for communication with MSP430G2553
- Natively pairs with our **Raspberry Pi Camera Module 3 NoIR**



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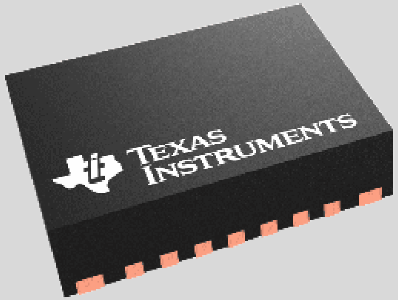
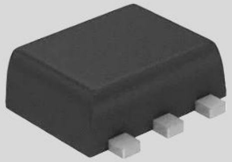
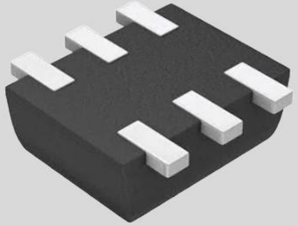
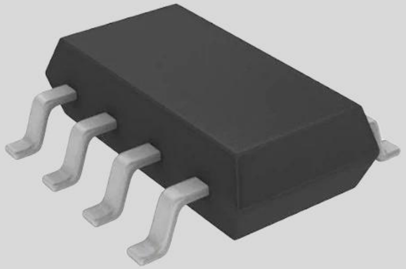
Voltage Regulator Comparison



Aspect	MP1479	LM2596	LM2678	TPS54JA20
Brand	Monolithic Power Systems	Texas Instruments	Texas Instruments	Texas Instruments
Input Voltage Range	4.2V to 18V	4.5V to 40V	8.0V to 40V	2.7V to 16V
Output Voltage Range	0.8V to 10V	1.2V to 37V	1.2V to 37V	0.9V to 5.5V
Max Output Current	1A	3A	5A	12A
Switching Frequency	800kHz	150kHz	260kHz	600kHz-1MHz
Price	$1.62	$5.20	$5.67	$2.24







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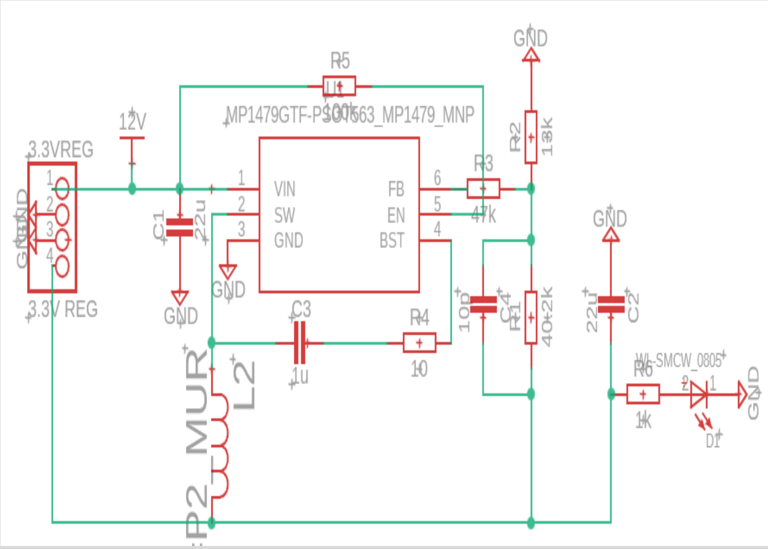
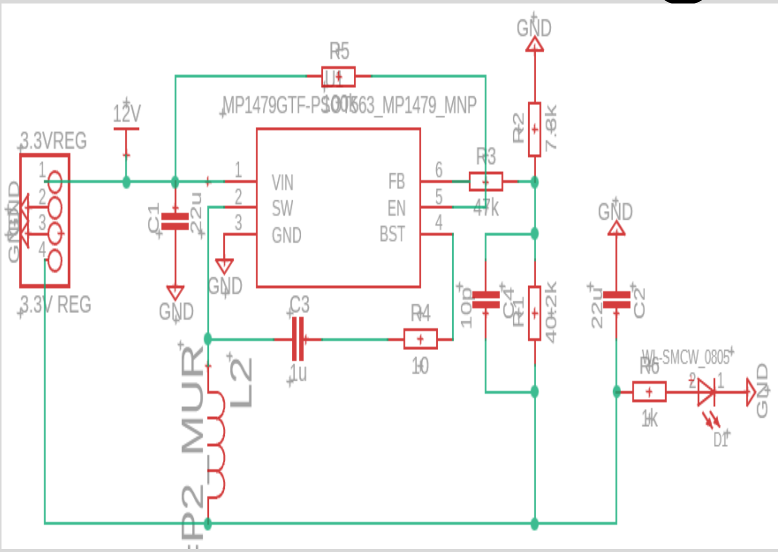
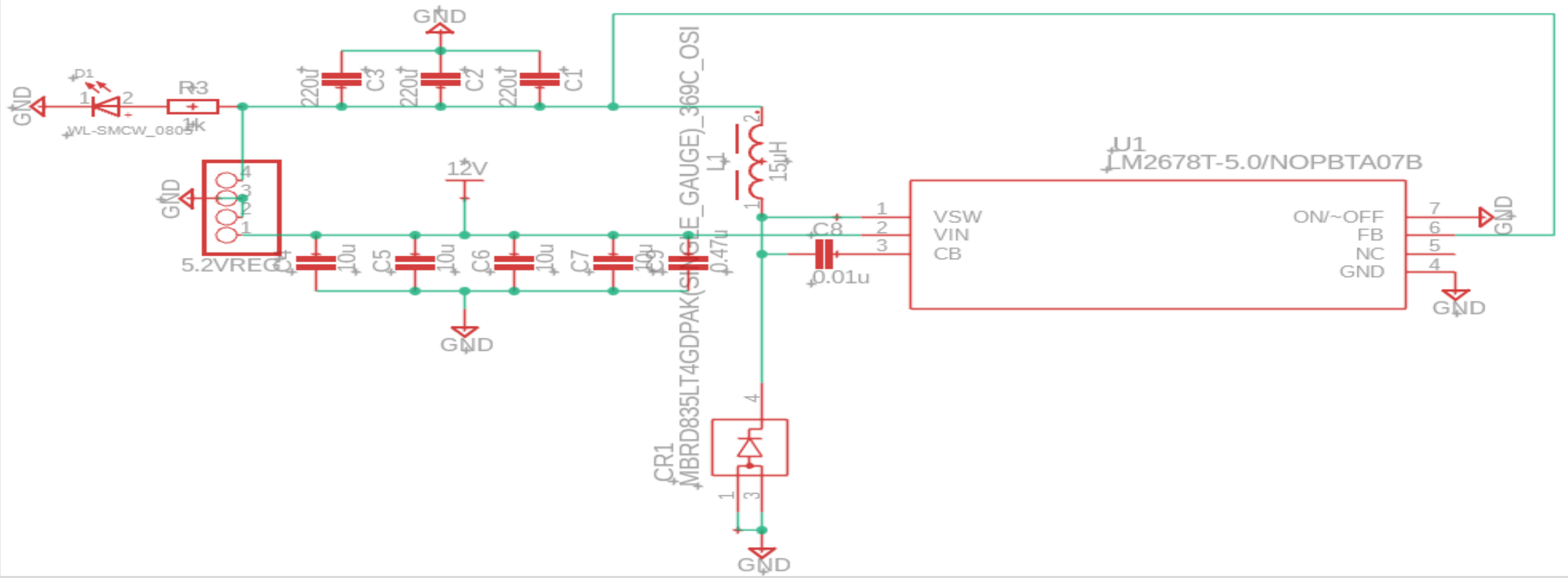
PCB Design



3.3V Schematic



5.2V Schematic



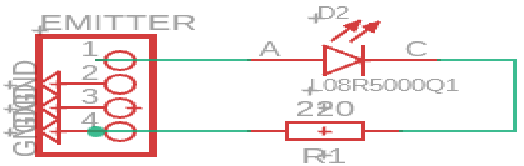
5V Schematic

Power Boards

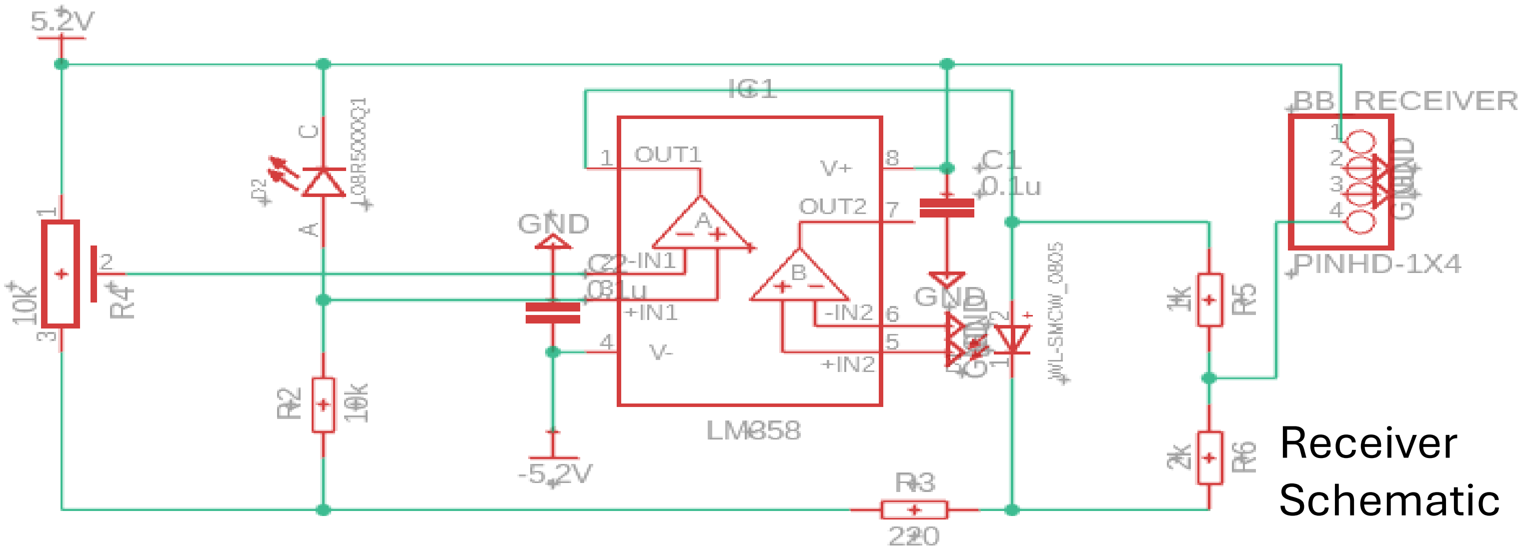
- 12V DC input, diverged power output
- 3.3V up to 1A Output to MSP430 and Pressure Pad Sensor
- 5.2V up to 1A Output to Proximity Sensor and Break Beam System
- 5V up to 5A Output to Raspberry Pi
- Separation of power assists with troubleshooting and repairs
- Power LED Indicator

Jeffrey | EE

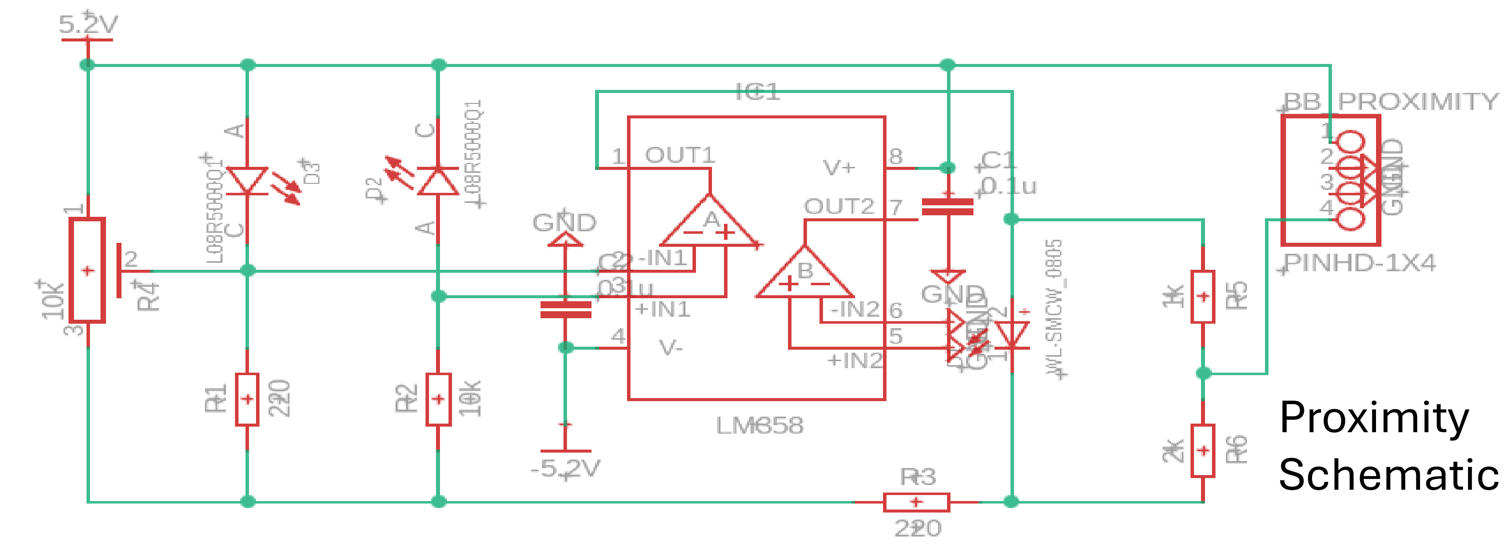
PCB Design



Emitter Schematic



Receiver Schematic



Proximity Schematic

Optical Boards: Proximity, Break Beam Receiver, and Emitter Sensors

- Infrared (IR) sensor for initial detection
- Dedicated headers for 5.2V power input to proximity and receiver
- Transmission headers for output signal connected to respective GPIO pins of MSP430

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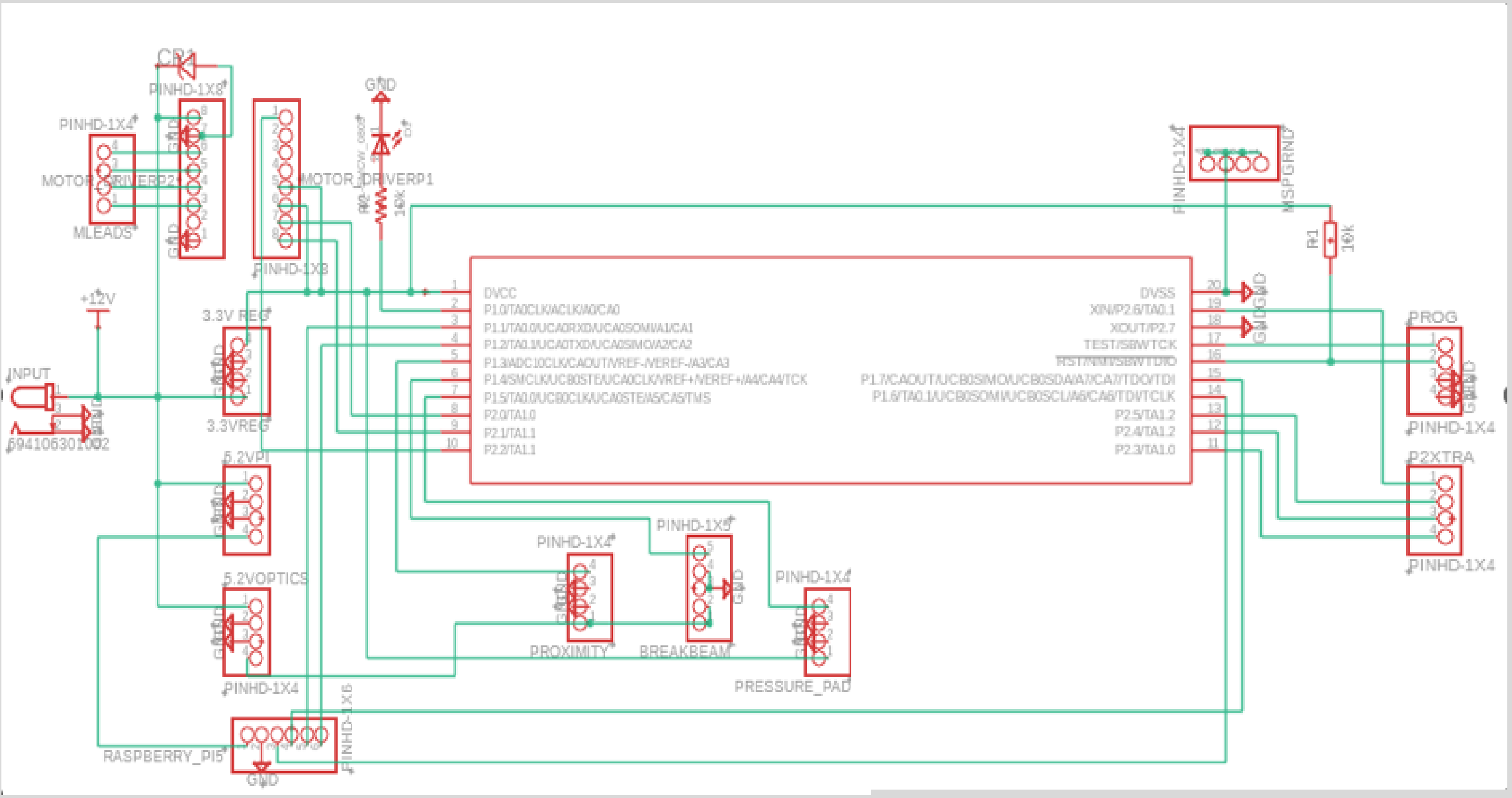
PCB Design



Main Board

- 120V AC Outlet adapted to 12V DC input routed to motor driver and voltage regulators
- MSP430 routed to all peripherals such as the sensors, Raspberry Pi 5, and motor driver
- Extra ground pin headers along with headers routed from MSP430 and Raspberry Pi 5 for troubleshooting and future-proofing

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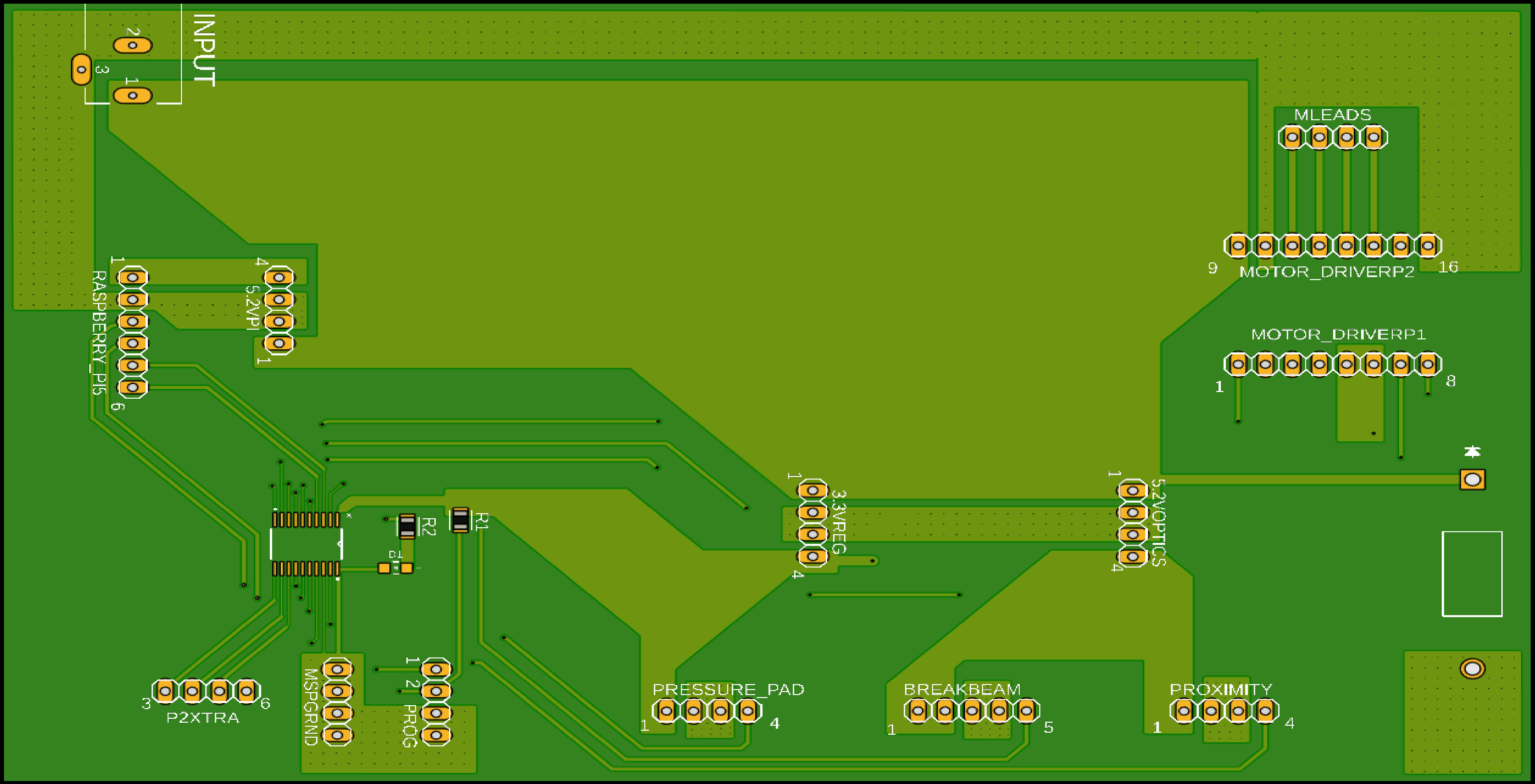
PCB Layouts – Main PCB



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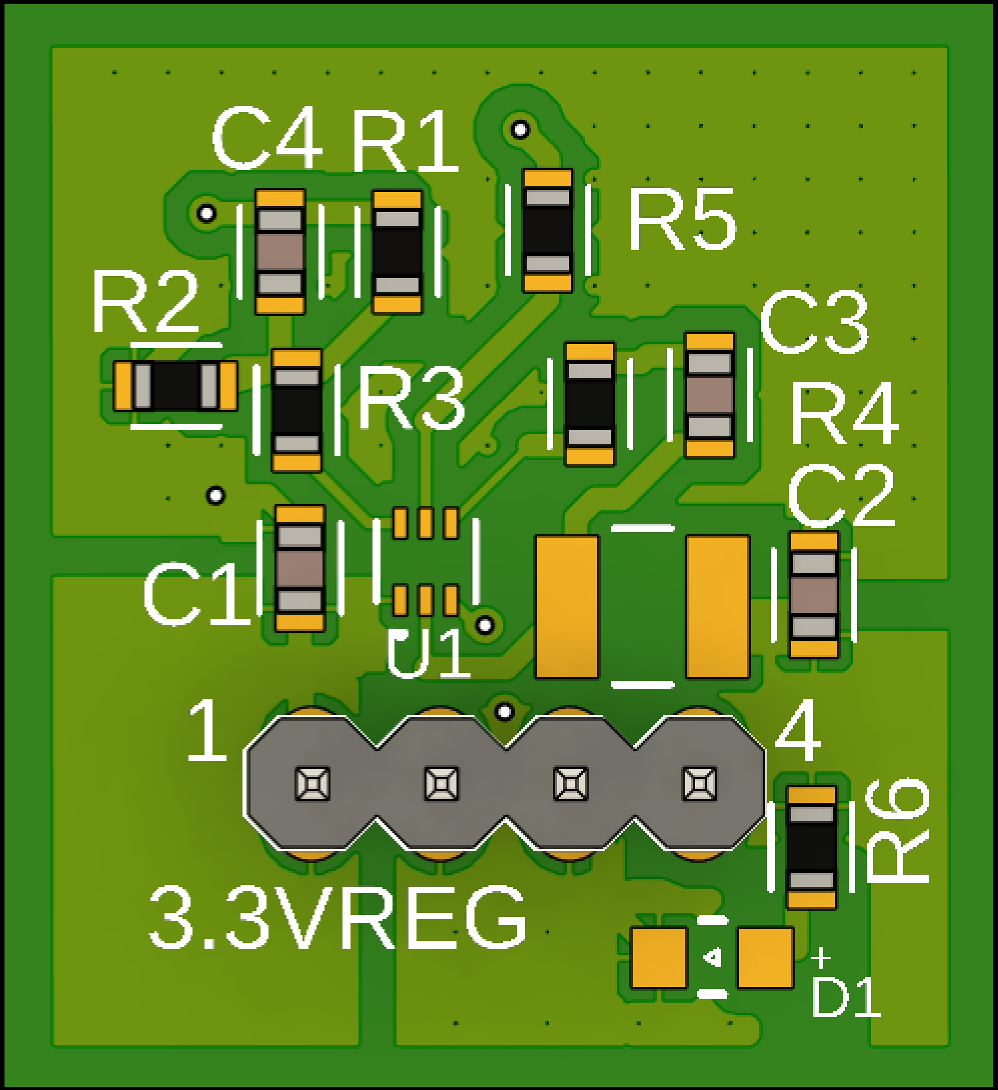
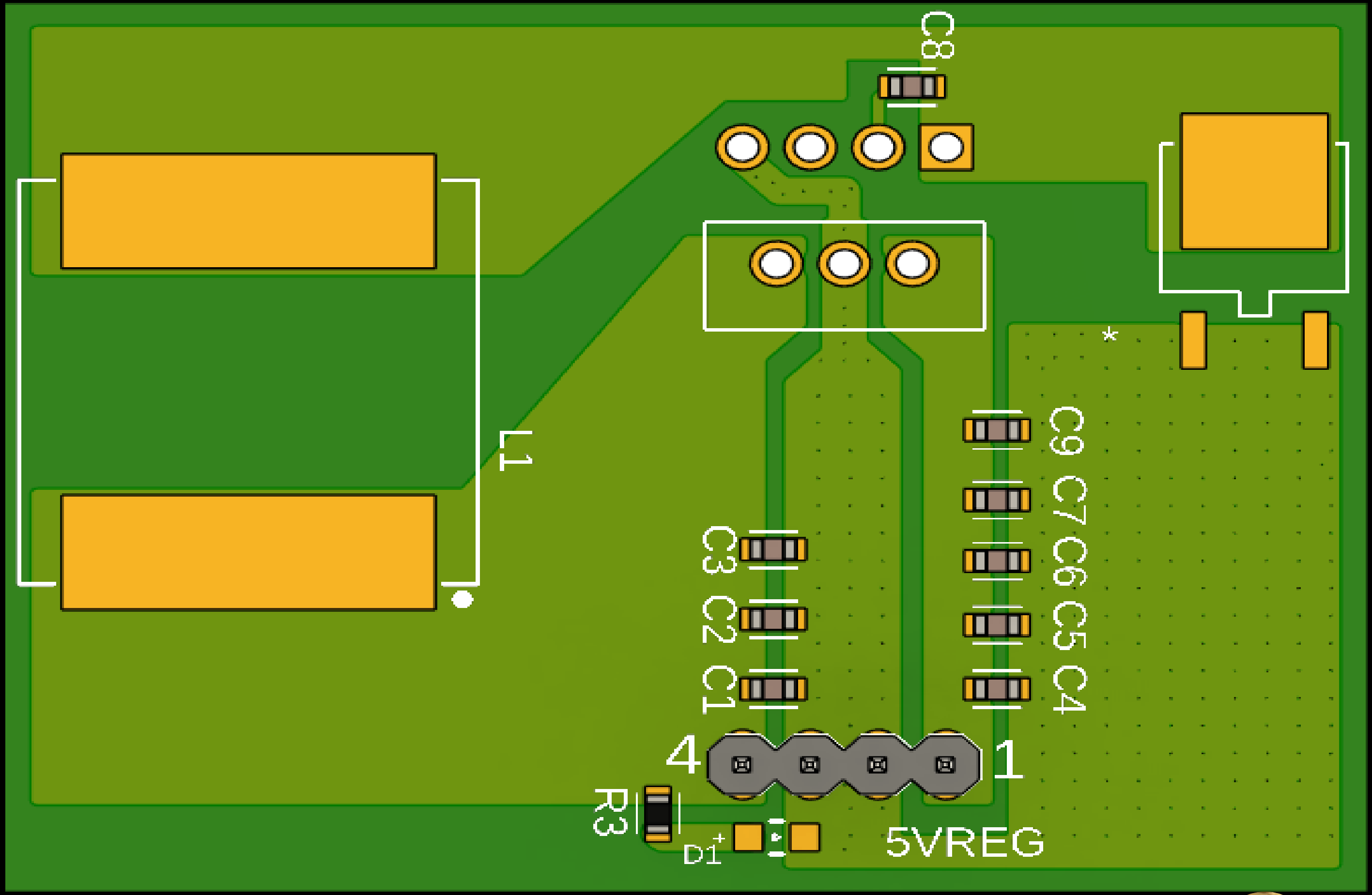
PCB Layouts – Voltage Regulators





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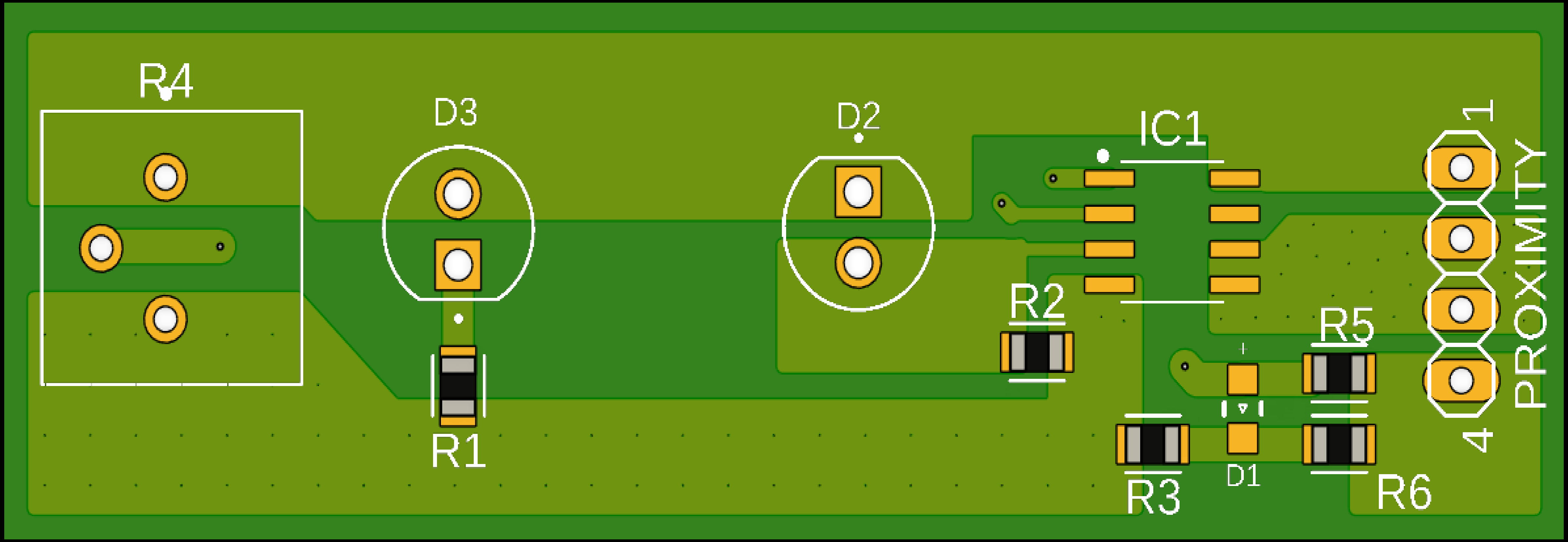
PCB Layouts – Optics Proximity Sensor



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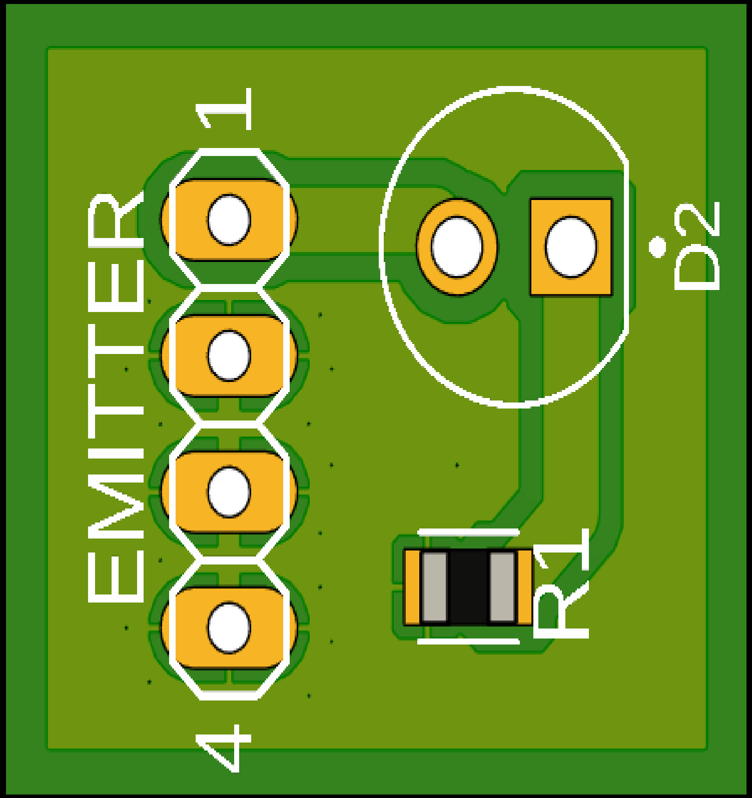
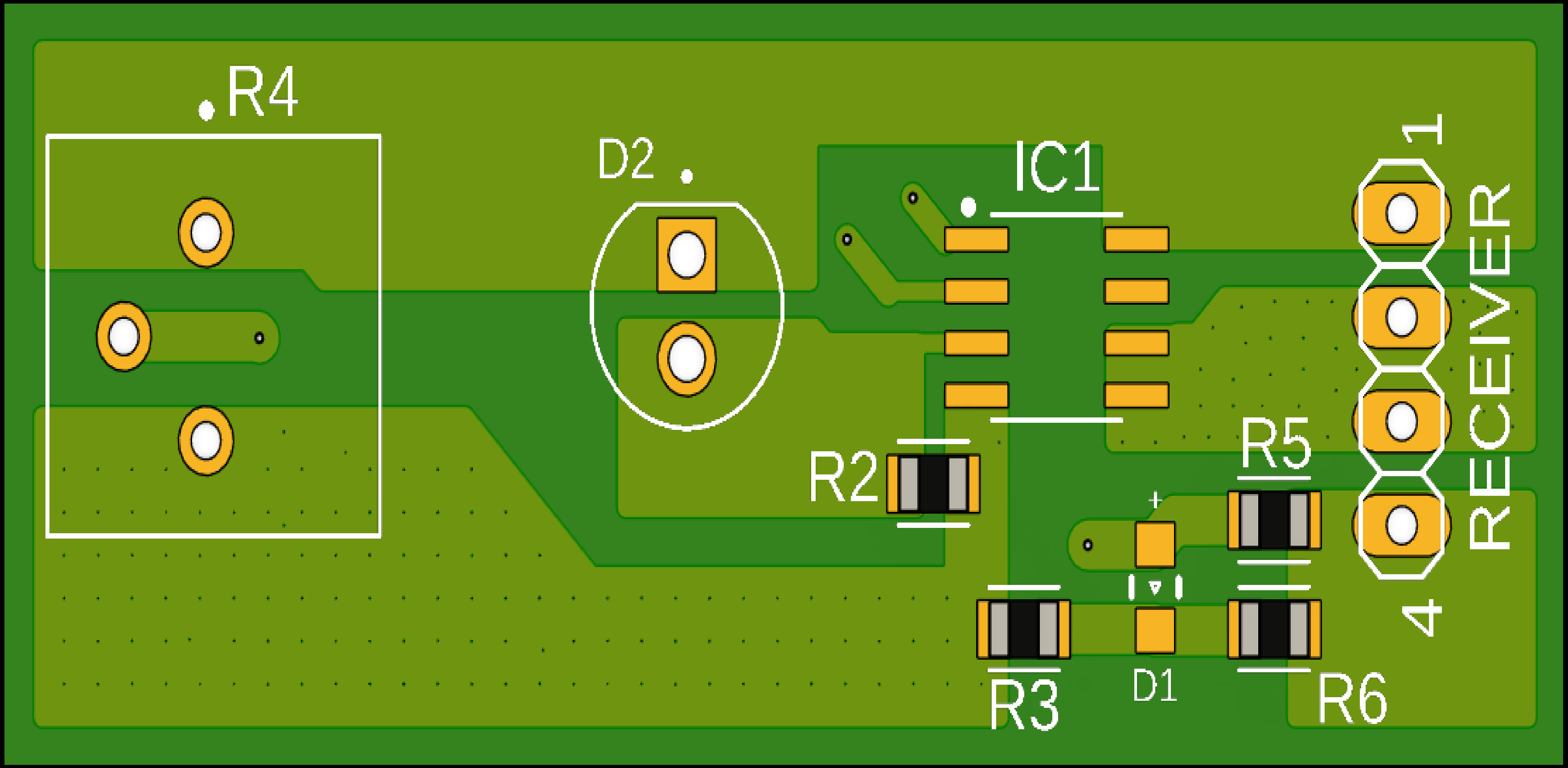
PCB Layouts – Optics Break Beam Sensor





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Object Detection Model Comparison

Feature	YOLO	Faster R-CNN	SSD
Detection Speed	Very fast, real-time	Slowest	Fast
Inference Time	Very fast, under <100ms	Very slow	Fast, but slower than YOLO
Accuracy	High	Best	Moderate / High, depends on config
Processing Power Required	Low, can run on SBCs	High, requires powerful GPUs	Moderate, can run on SBCs
Model Size	Small	Large	Moderate
Input Resolution	Best with small sizes	Requires high resolution	Works with various sizes

Christian | CPE

YOLO Object Detection

The chosen object detection model is **YOLO11**

- Successfully detects cats within field-of-view with accuracy between 75% - 95%
- Currently running between 2.0 to 2.5 fps
- NCNN conversion allows Pi to reliably run XL weight without freezing or crashing
- Adds a bounding box and classification label around detected object
- NoIR camera can detect objects at all times of day

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Mobile App Framework Comparison

Feature	Flutter	React Native	Ionic	Kotlin Multiplatform
Performance	Very high, near-native	Very high, near-native	Moderate, WebView based	Native
UI Customization	Very customizable, widgets for complex UIs	Very customizable, more effort for complex UIs	Limited, web-based UI	Very customizable, requires platform-specific UI code
Ease of Use	Moderate	Low	High	Moderate
Coding Language	Dart	JavaScript	HTML / CSS / JavaScript	Kotlin

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Mobile App Hosting Service Comparison

Feature	Firebase	Heroku	DigitalOcean
Security	Built-in authentication, SSL, etc.	Add-ons for authentication, SSL, etc.	Full control, but requires manual setup
Infrastructure Control	Limited, managed service	Limited, managed service	Full control, self-managed
Scalability	High, especially for mobile apps	High, can become costly at scale	High, can scale with virtual machines
Ease of Use	Very easy, direct app integration	Easy, Git-based deployment	Moderate, needs server management
Pricing	Free, higher cost for scaling	Free, higher cost for scaling	~$5 - $7 / month

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Mobile Application Technologies

Flutter is an open-source SDK created by Google for building mobile and web application UIs

- Uses Dart programming language
- Easy to set up app with the built-in widget library and UI color themes
- Multiplatform, supports both iOS and Android in one codebase
- Hot reloading allows applying changes to the code without restarting debugging window

Firebase is a platform owned by Google that offers backend services for mobile and web applications

- Firebase Authentication handles logins, logouts, and registration
- Firebase Firestore is a NoSQL cloud database
    - Stores user data, activity logs, and favorited images status
- Firebase Storage is a cloud storage service
    - Stores images sent from the Raspberry Pi
- Firebase Cloud Messaging allows sending push notifications

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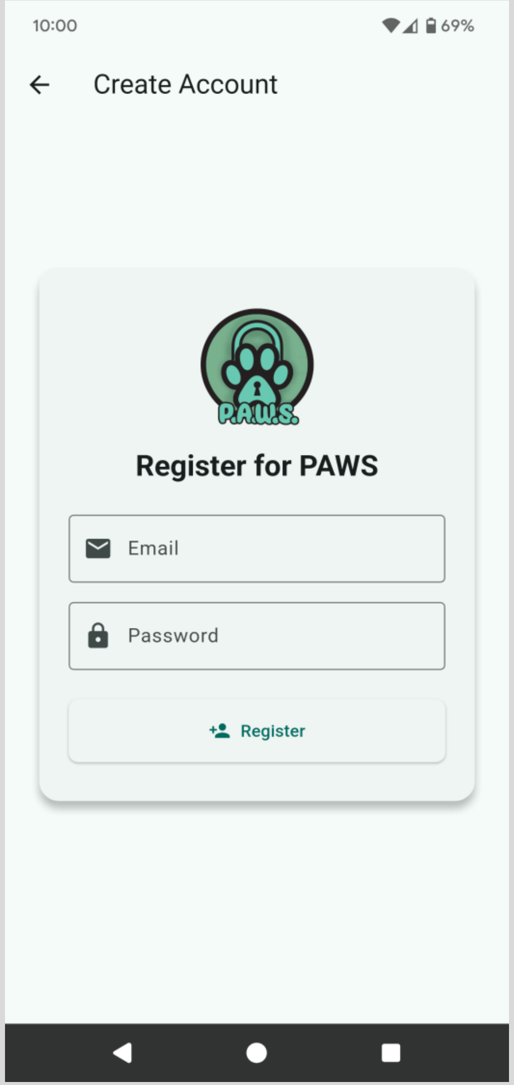
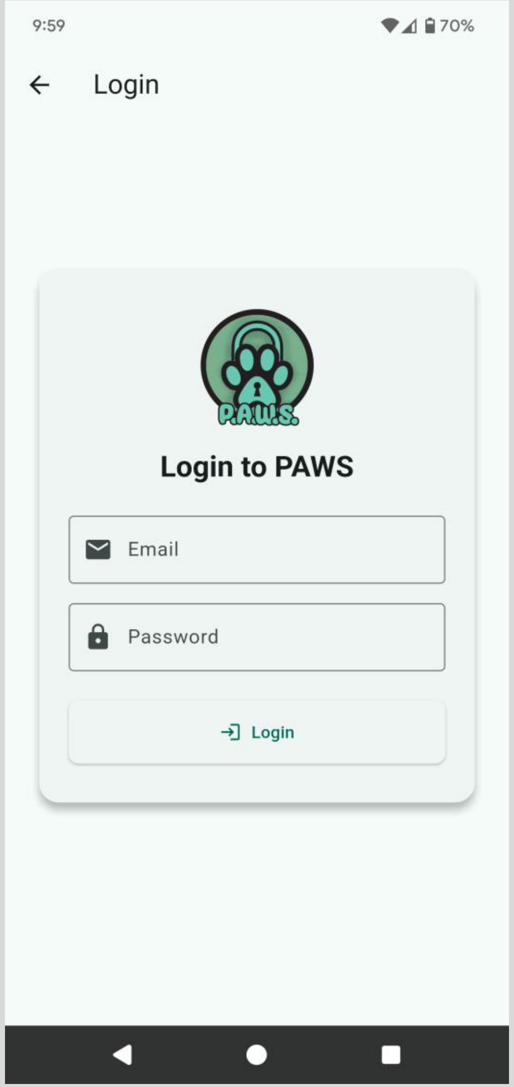
Mobile Application Design





Login and Signup Pages:

- Users are asked to enter a valid email and password
- Users will be able to change their password inside the app
- Firebase Authentication handles both signups and logins, plus storing user credentials

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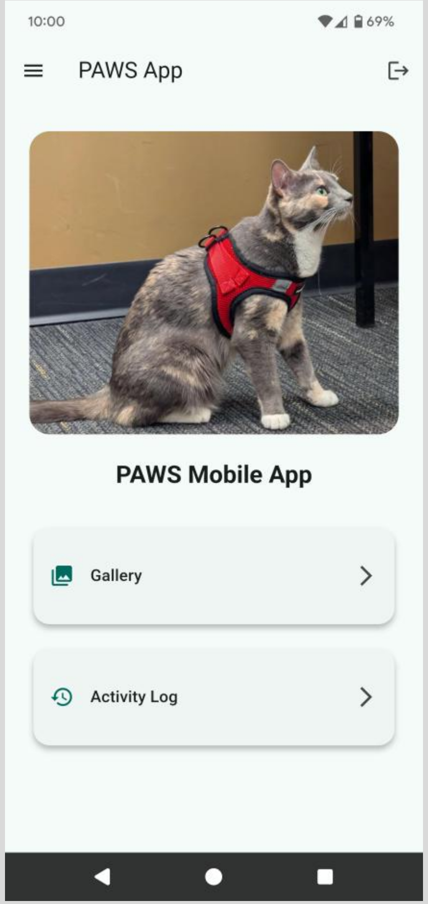
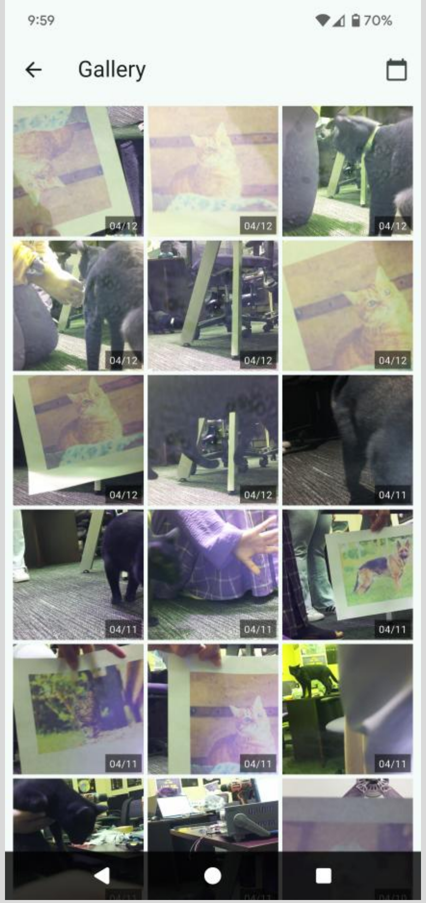
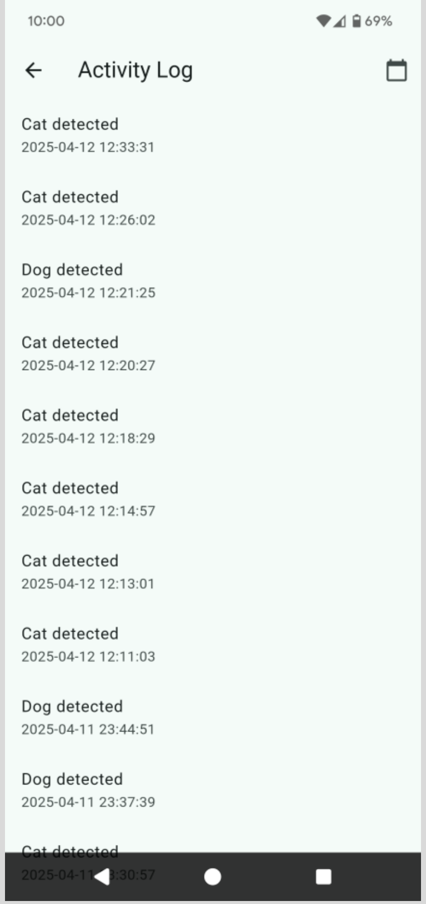
Mobile Application Design







Home Page:

- The home page is the initial landing page for logged in users
- Navigation to other pages can be done in the side navbar or large tabs on home

Gallery Page:

- Gallery of images sent from the Pi whenever a cat or dog is detected (min every 5 minutes)
- Users can favorite or delete images

Activity Log Page:

- Simple text page showing recent P.A.W.S. enclosure activity
- Each log shows whether a cat or dog was detected, and when it happened

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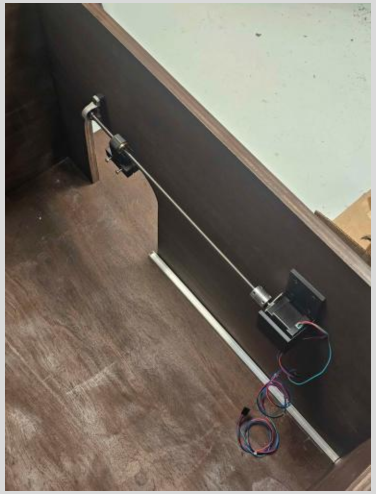
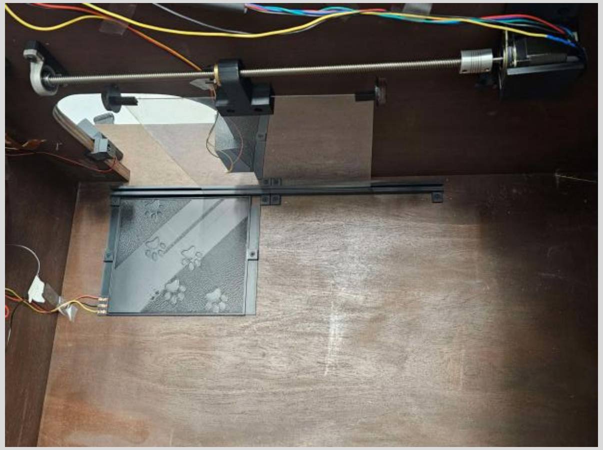
Railing Improvement

Demo of our old guard railing

Demo of our new guard railing



Inside view of old guard railing



Inside view of new guard railing

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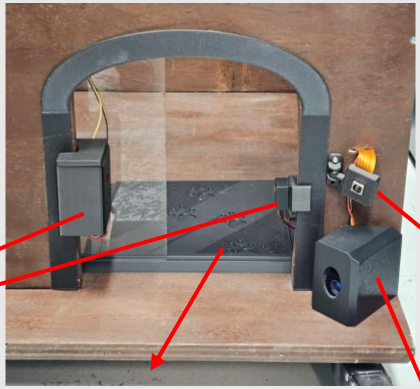
Complete Look

Hardware - Mechanical

Door Clamp and Pi Housing

Electronics Housing



Break-Beam Sensor

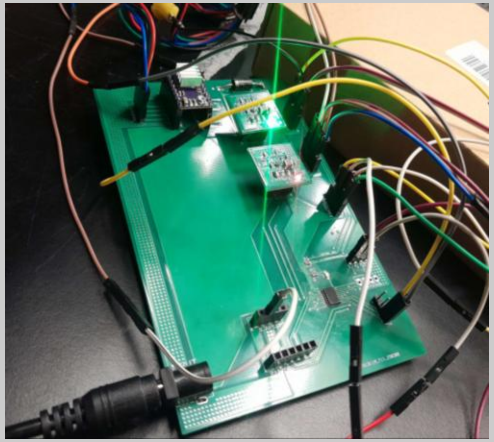
Pressure Pad

Camera

Proximity Sensor

Hardware – Electrical/Optical

Main PCB and Power PCBs



Optical PCBs

Break beam receiver

Break beam emitter

Proximity

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Budget

Component(s)	Budget	BOM
Fully-enclosed rectangular structure	$74.99 (1)	$165
IR Imaging camera	$25.99 (1)	$31.65
Plexiglass sheets	$10.99 (5)	$10.64
Motorized rail-system (all parts included)	$35.99 (1)	$51.07
IR LED	$ 7.95 (25)	$11.42
Photodetector	$5.49 (20)	$5.49
Velostat pressure sensitive sheet	$9.99 (2)	$10.65
Misc. Hardware (screws, wiring, etc.)	$14.99 (1)	$60
Single-Board Computer (Raspberry Pi)	$80.99 (1)	$99.23
Microcontroller	$15.99 (1)	$19.04
Custom PCB	$85.99 (7)	$223.22
Overall Total (approximately)	$405.01	$687.41

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Work distribution

Member	Task
Primary: Luana Secondary: Christian	○ Proximity Sensor Design ○ Break-Beam Sensor Design ○ Housing Design
Primary: Kinza Secondary: Luana	○ MSP430 Software Integration of Sensors, Motor Control ○ MSP430-Pi UART Communication ○ Mobile App
Primary: Jeffrey Secondary: Kinza	○ PCB Design/Assembly/Testing ○ Wiring/Soldering Components
Primary: Christian Secondary: Jeffrey	○ Mobile App ○ Raspberry Pi Integration ○ Machine Learning Algorithm

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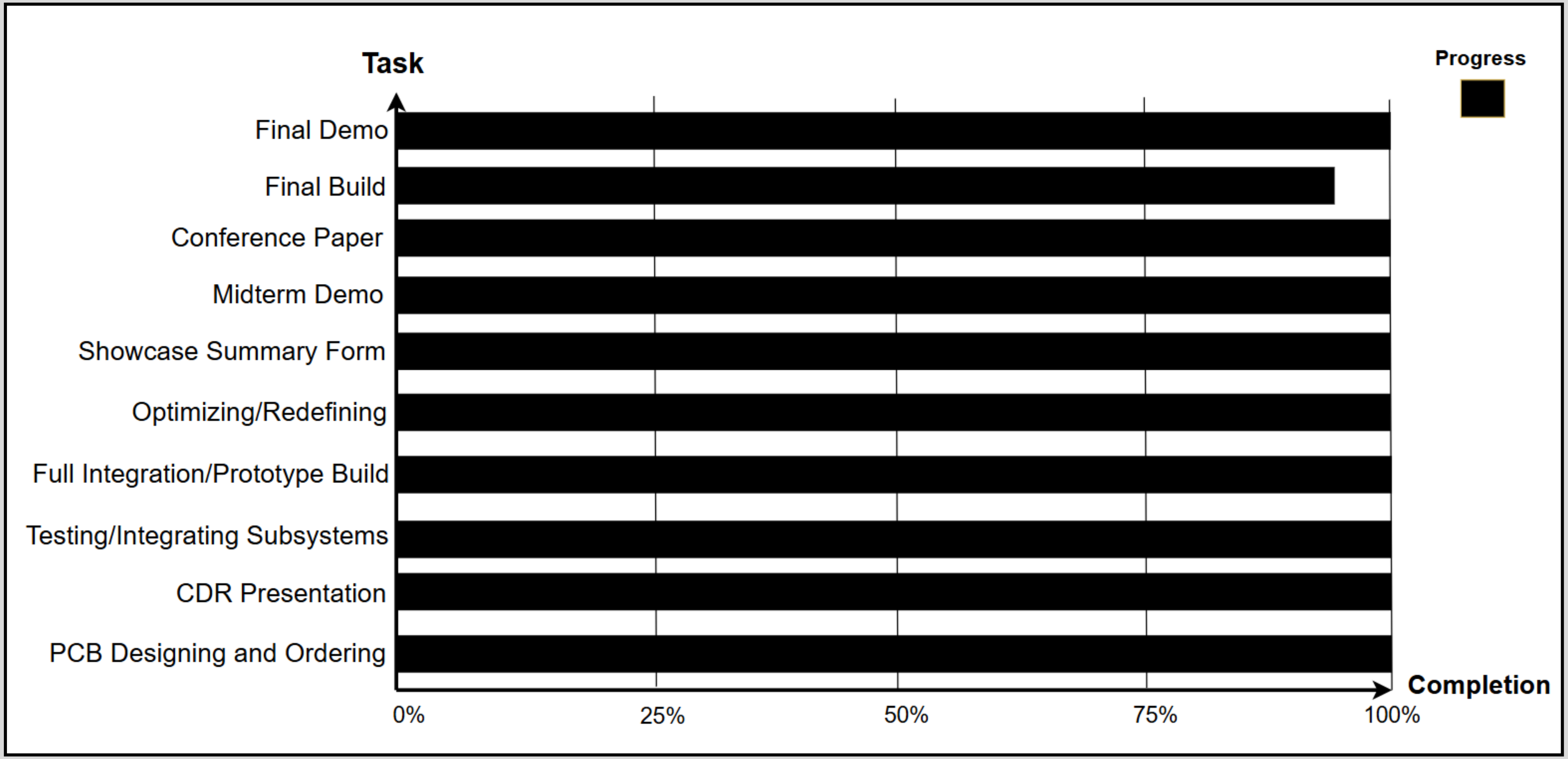
Progress and Plan for Completion



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Thank you for listening!