



P.A.W.S.

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

Group 9:

Luana Capel

Kinza Rashid

Jeffrey Sotello

Christian Williams

Meet The Team



Luana Capel

Photonic Science
and Engineering



Kinza Rashid

Computer
Engineering



Jeffrey Sotello

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



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



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



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



System Engineering Requirements

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



Physical Enclosure

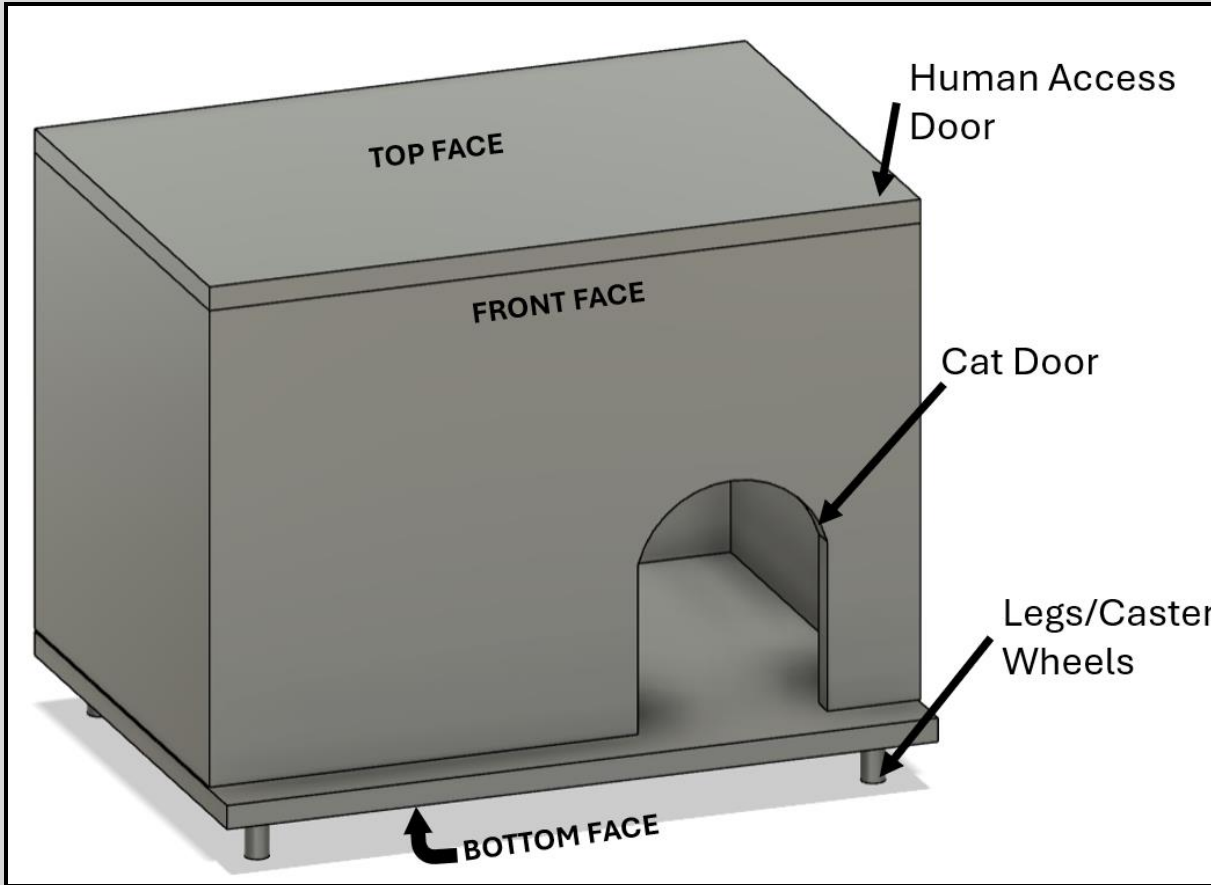


Fig 1. 3D model of physical enclosure

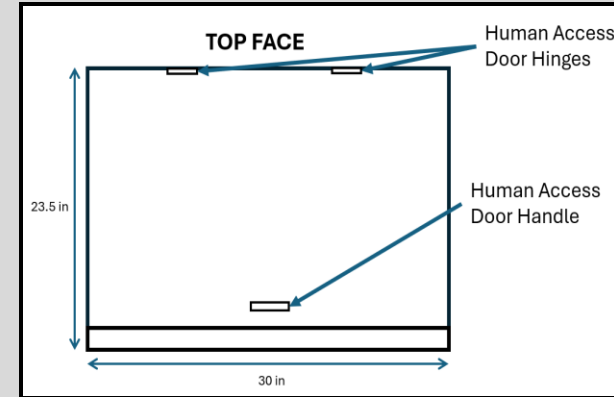


Fig 2. 2D view of outer top face of enclosure

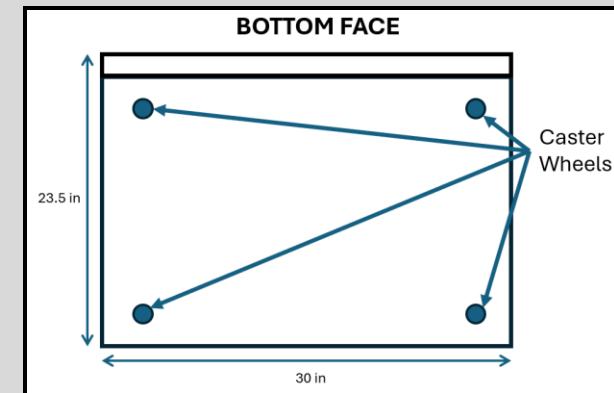


Fig 3. 2D view of outer bottom face of enclosure

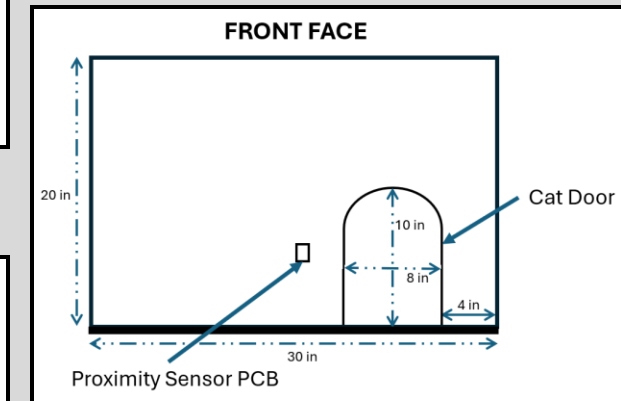
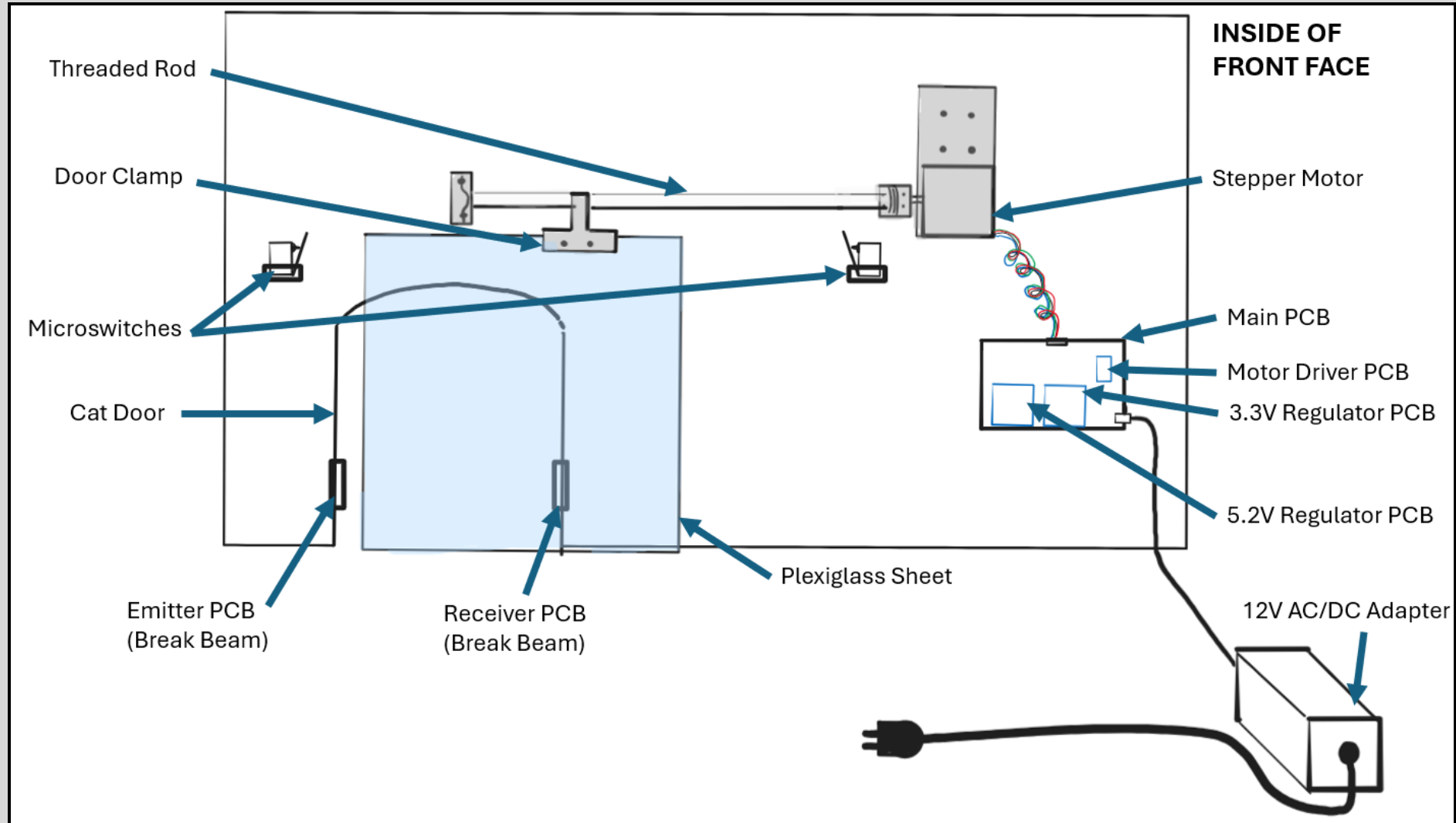


Fig 4. 2D view of outer front face of enclosure



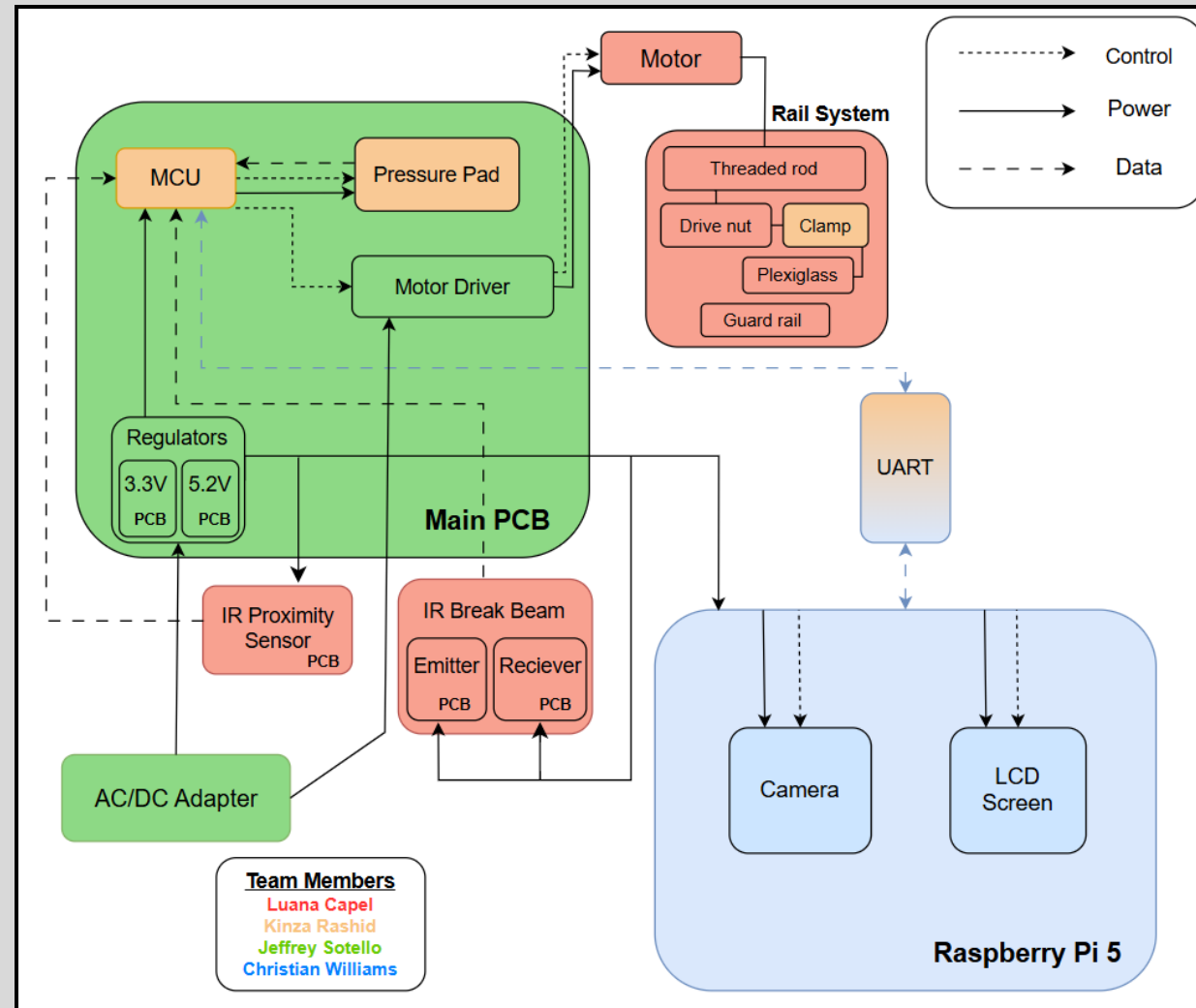
Physical Enclosure – Cont.



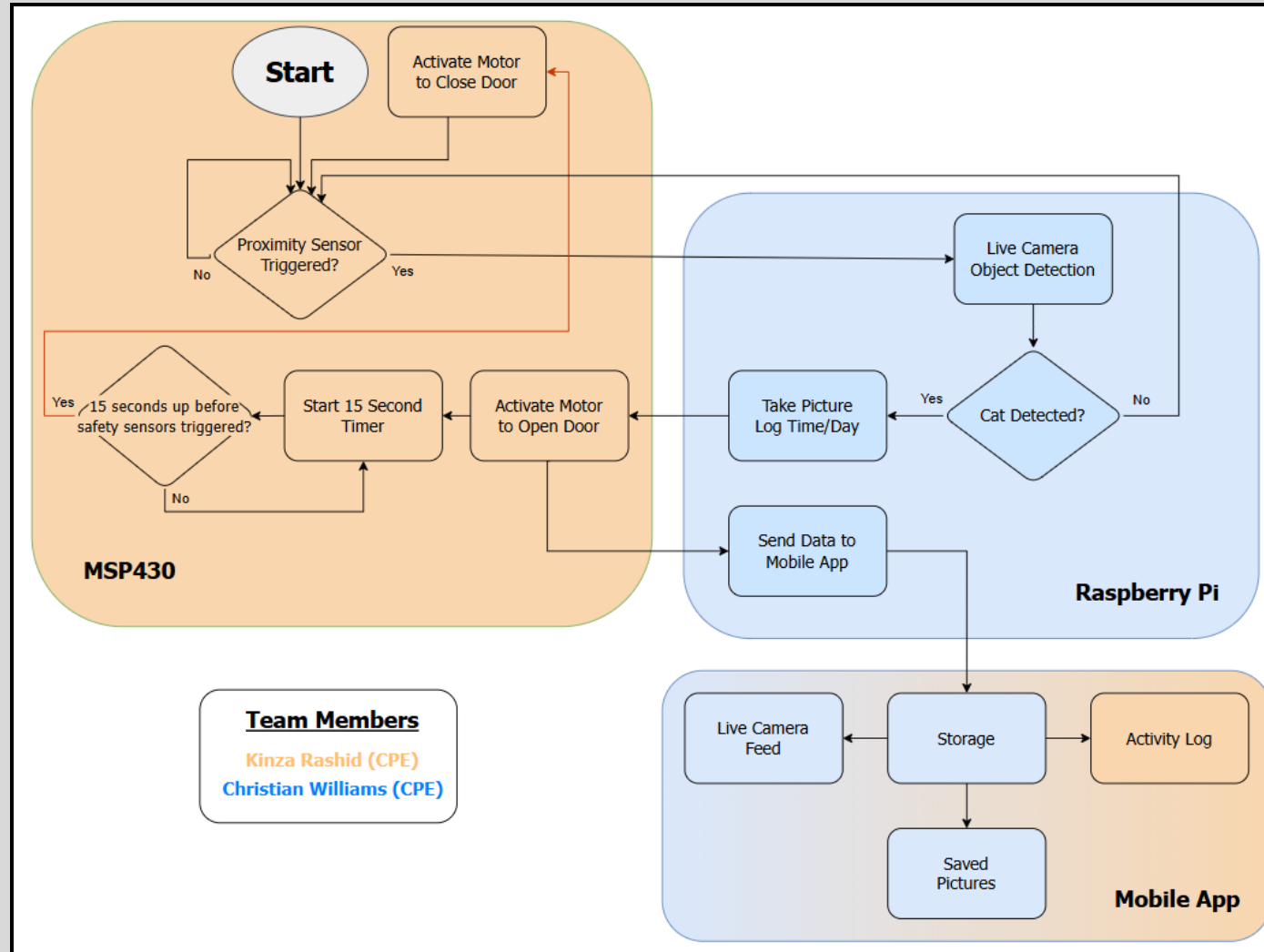
2D view of inner front face of enclosure



Hardware Block Diagram

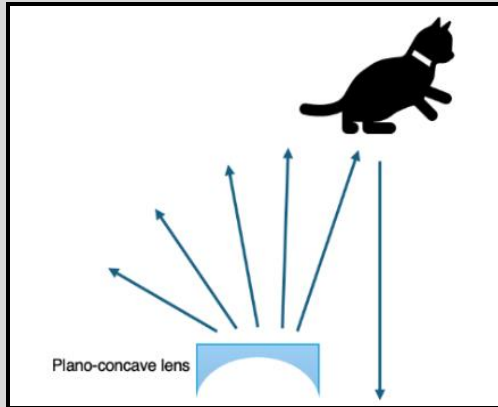


Software Block Diagram



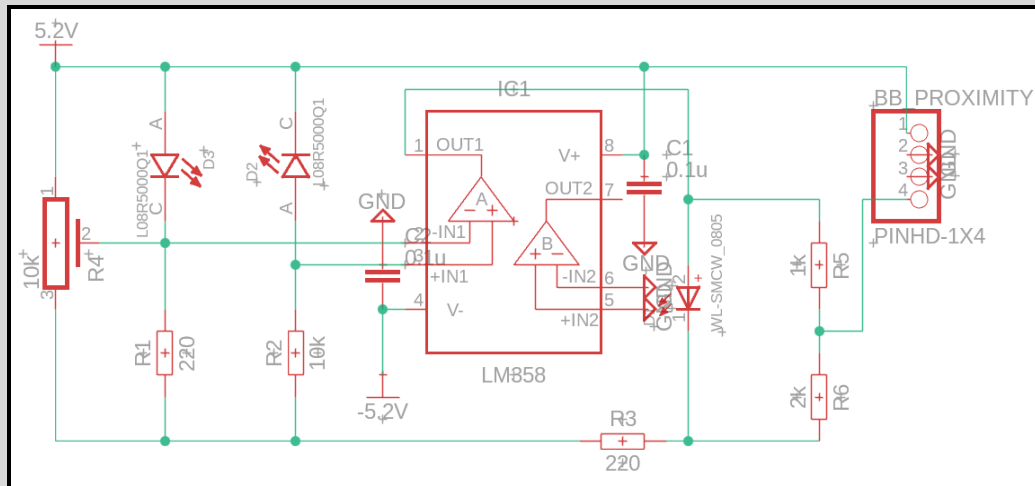
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Proximity Sensor

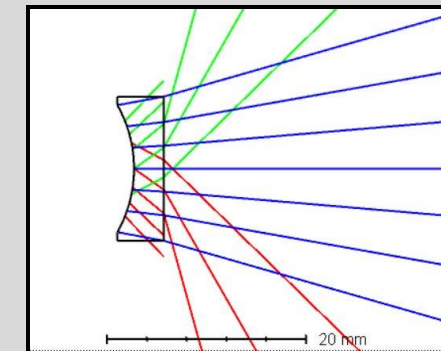
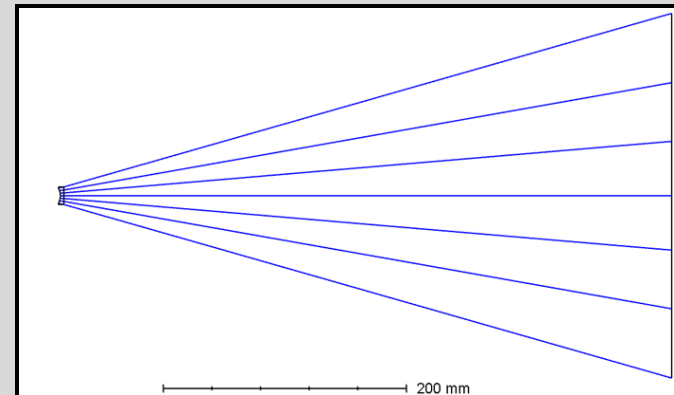


- FOV 60°
- Diameter = 25mm
- EFL = 21.6mm

	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

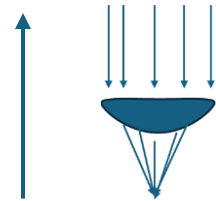
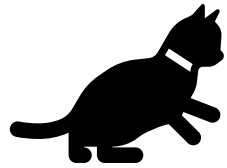
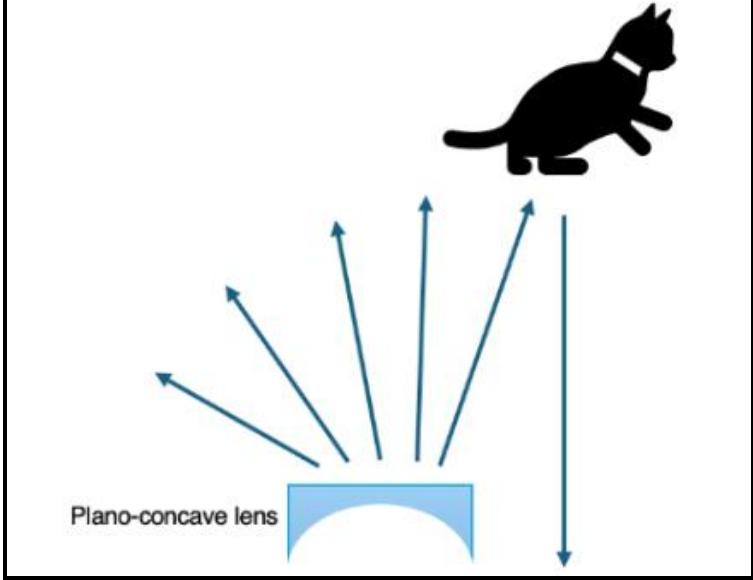


Overall Schematic of proximity sensor design

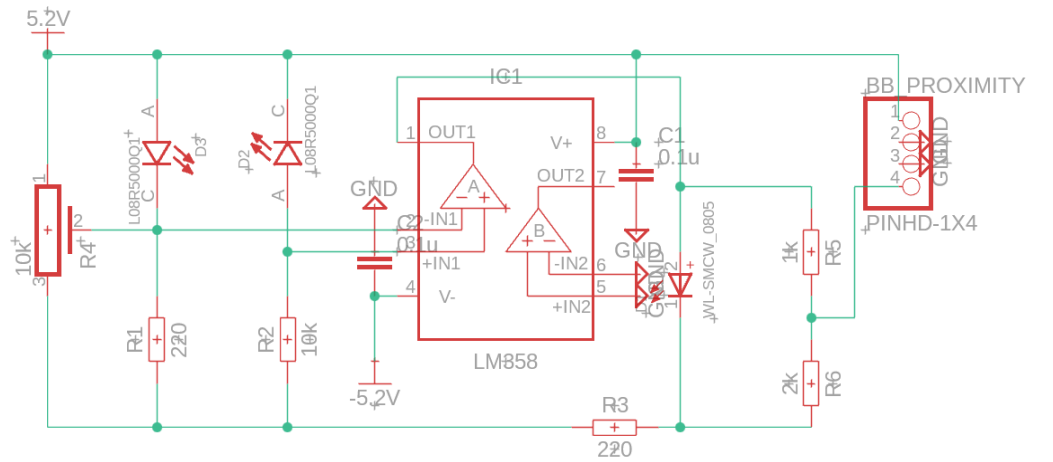
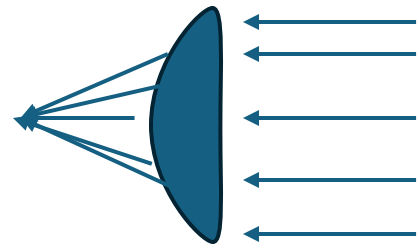
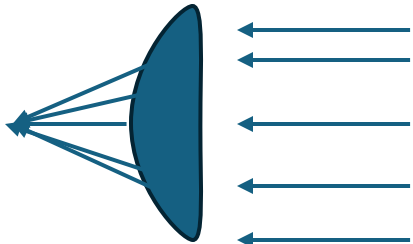
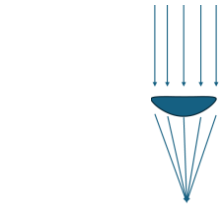


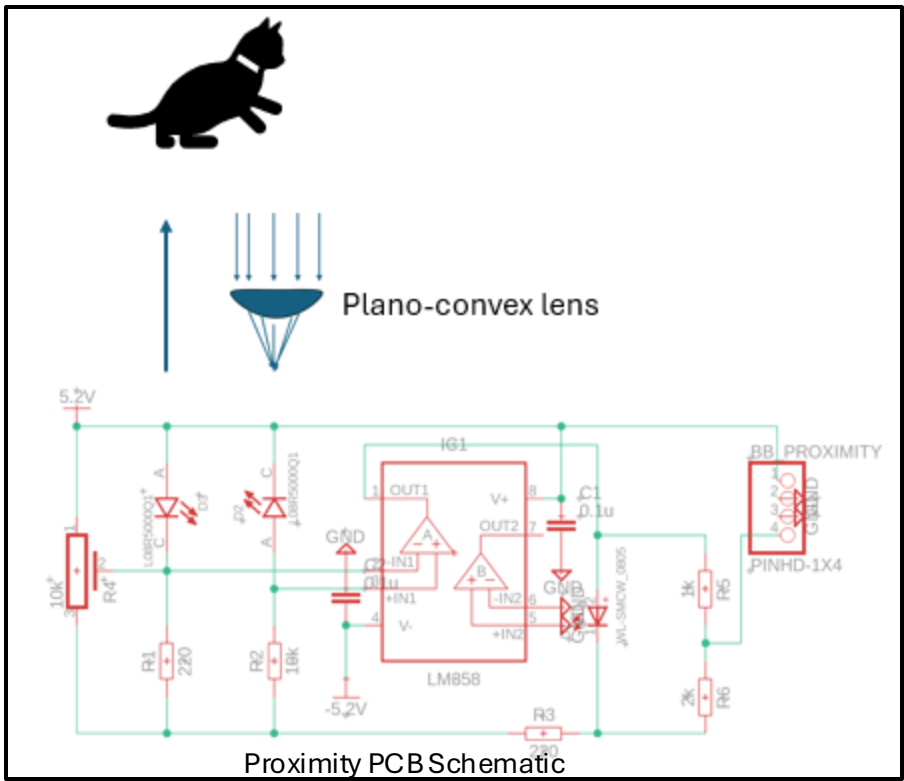
Lens Design on Zemax



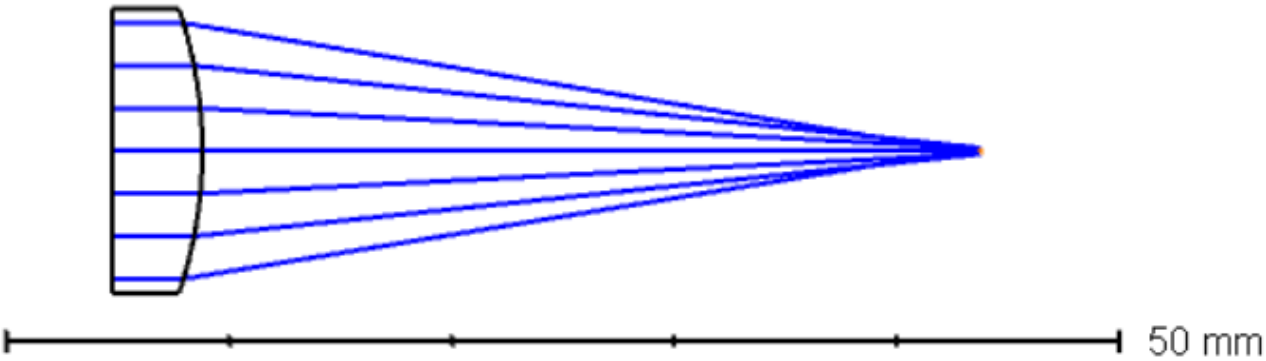


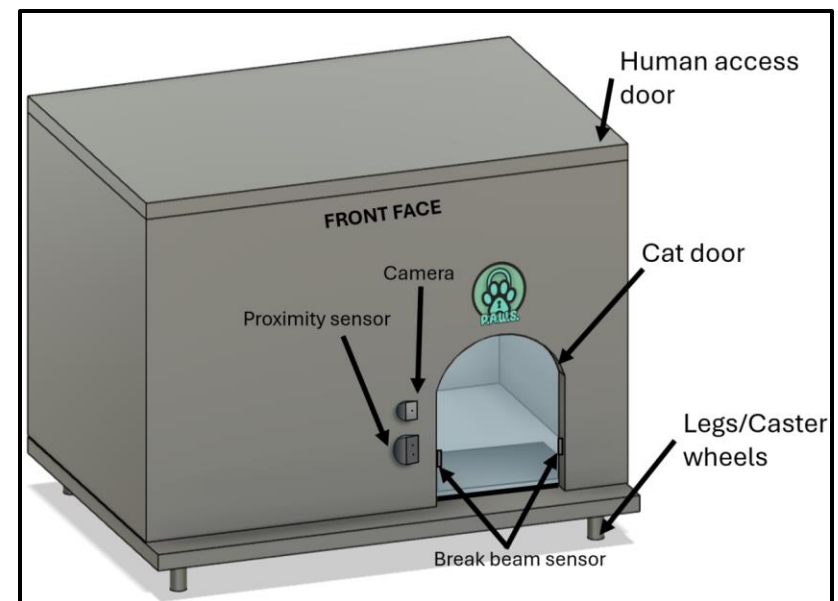
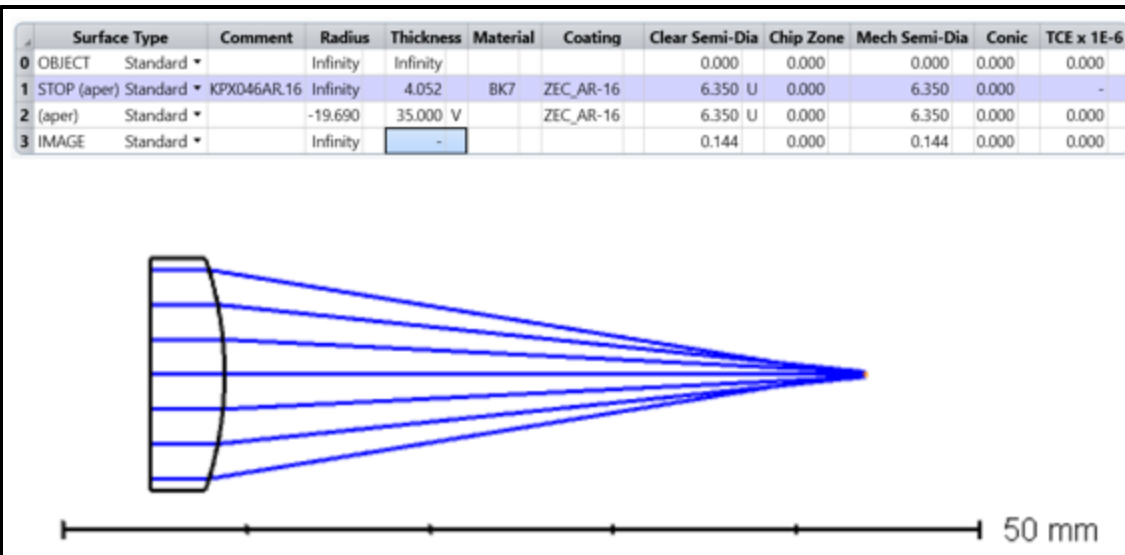
Plano-convex lens



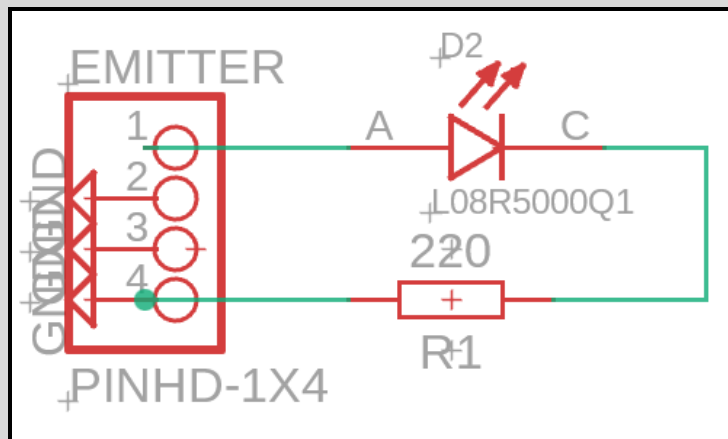
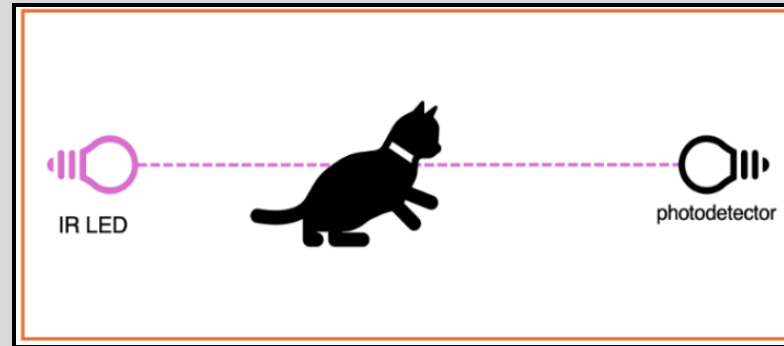


	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6
0	OBJECT	Standard ▾	Infinity	Infinity			0.000	0.000	0.000	0.000	0.000
1	STOP (aper)	Standard ▾	KPX046AR.16	Infinity	BK7	ZEC_AR-16	6.350 U	0.000	6.350	0.000	-
2	(aper)	Standard ▾	-19.690	35.000 V		ZEC_AR-16	6.350 U	0.000	6.350	0.000	0.000
3	IMAGE	Standard ▾	Infinity	-			0.144	0.000	0.144	0.000	0.000

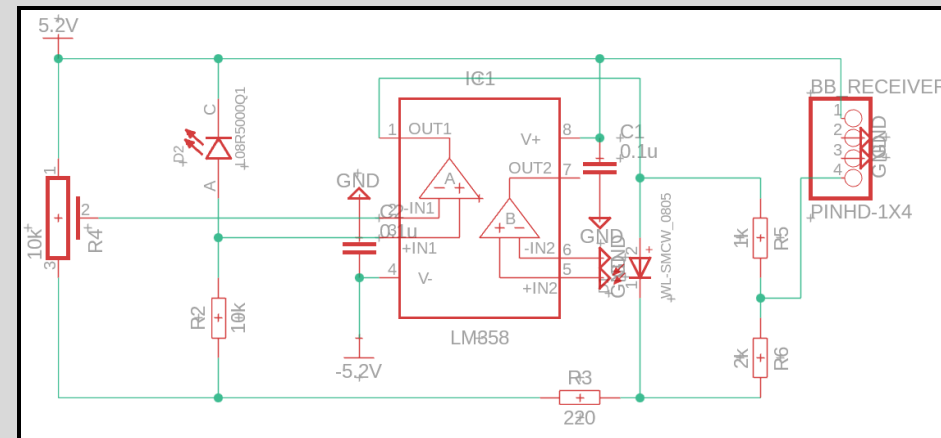




Break-beam Sensor



Emitter PCB Schematic



Receiver PCB Schematic

Overall Schematic of break-beam sensor design



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	\$	\$

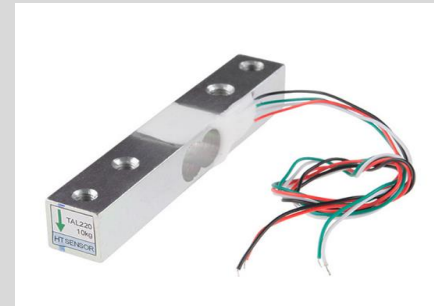


Fig 1. Load cell weight sensor

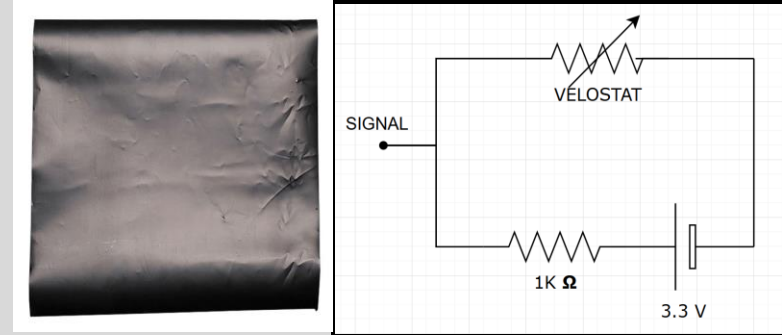


Fig 2. Velostat (left) and example of a velostat pressure sensor circuit

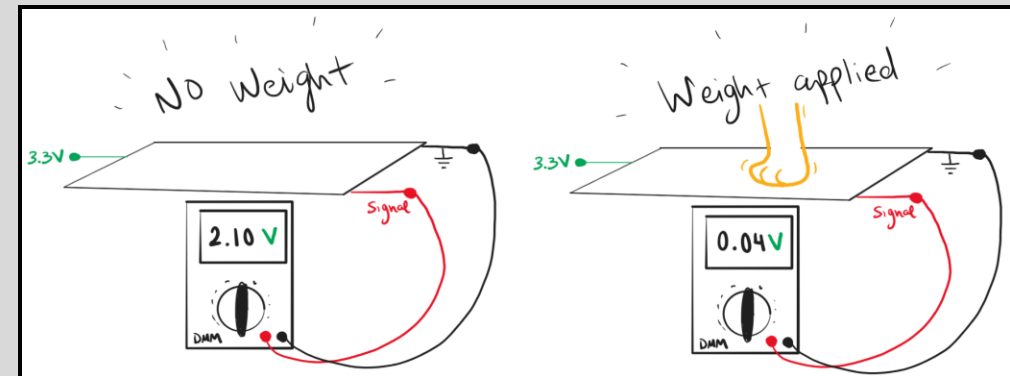


Fig 3. Velostat pad circuit voltage readings



Rail System Comparison

change/shorten script

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



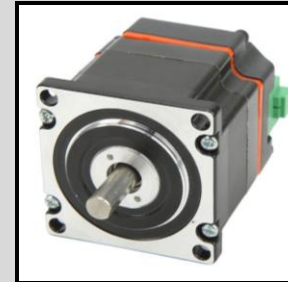
Motor Comparison

*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

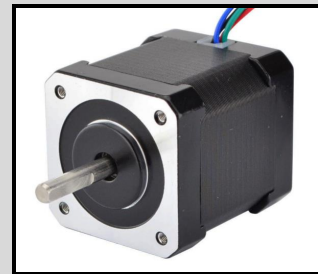
Servo



BLDC



Stepper



Motor Selection

Stepper Motor

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

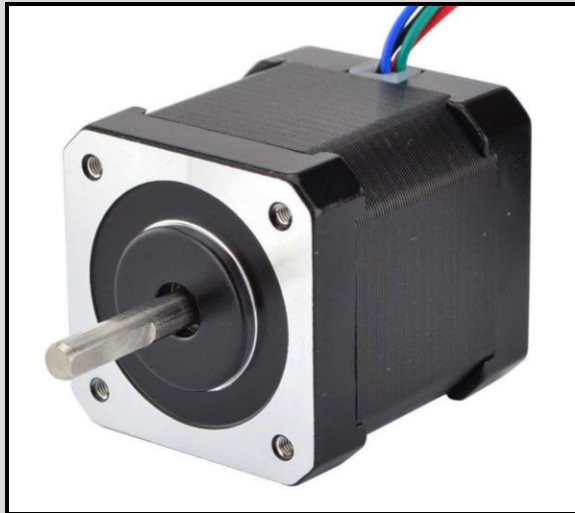


Fig 1. NEMA 17 stepper motor

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



Microcontroller Comparison

*Initial considerations (no longer in selection)

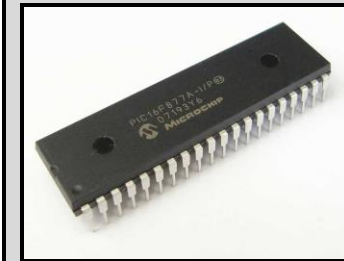
MCU	Advantages	Disadvantages	Price
*STM32	Powerful ARM-based	Complex development environment, steeper learning curve	\$\$
*ATmega328	Classic 8-bit, widely used	Limited processing power and memory	\$\$
ESP32	Built-in WiFi/Bluetooth, powerful dual-core processor, rich peripherals	Higher power consumption, 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



Microcontroller Selection

MSP430 Responsibilities

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

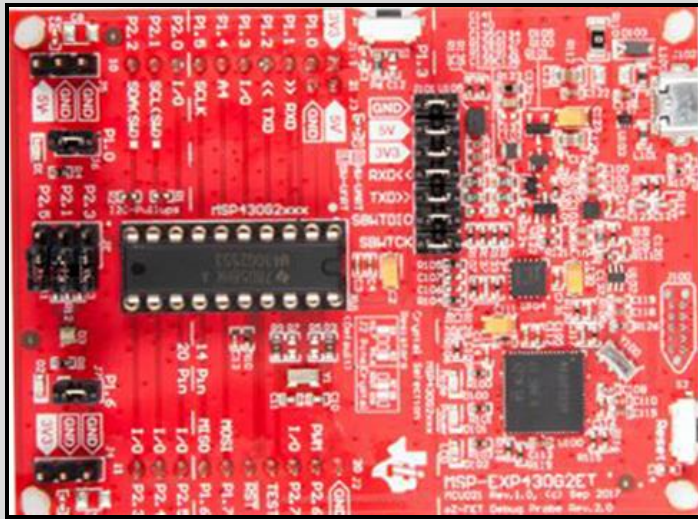


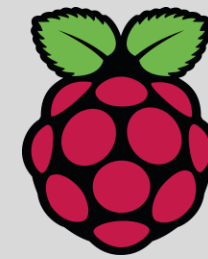
Fig 1. MSP430G2553 LaunchPad™ Development Kit

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



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



Christian | CPE

Single-Board Computer Comparison

Component	Raspberry Pi 4	Raspberry Pi 5	Coral Dev Board Mini	BeagleBone Black
CPU	Quad-core ARM Cortex-A72	Quad-core ARM Cortex-A76	Quad-core ARM Cortex-A35	ARM Cortex-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/8GB 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

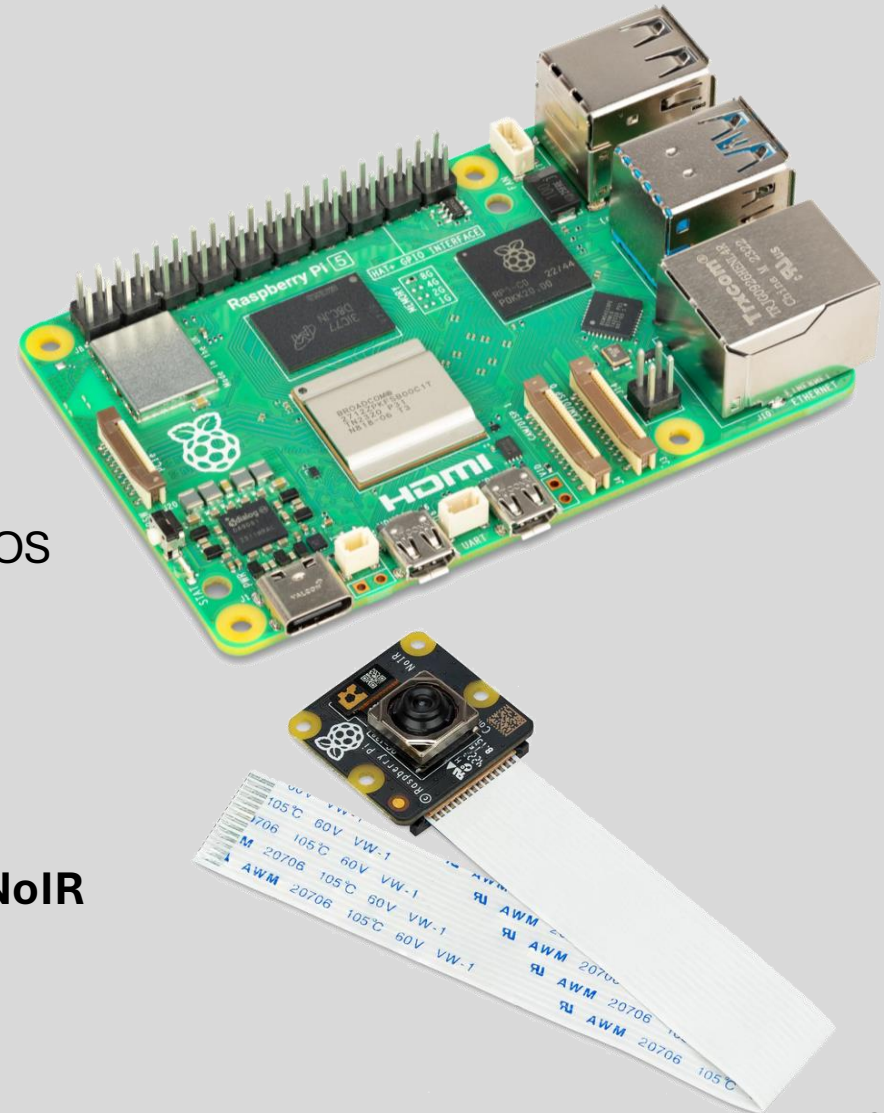


Christian | CPE

Single-Board Computer Selection

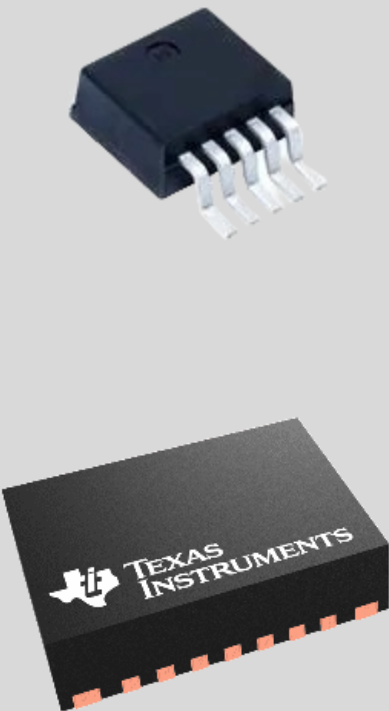
To handle the P.A.W.S. project's machine learning tasks, we chose the **Raspberry Pi 5 4GB**

- 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**

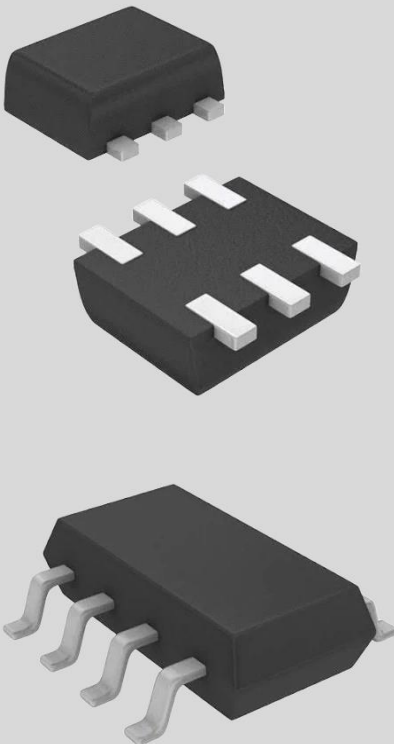


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Voltage Regulator Comparison

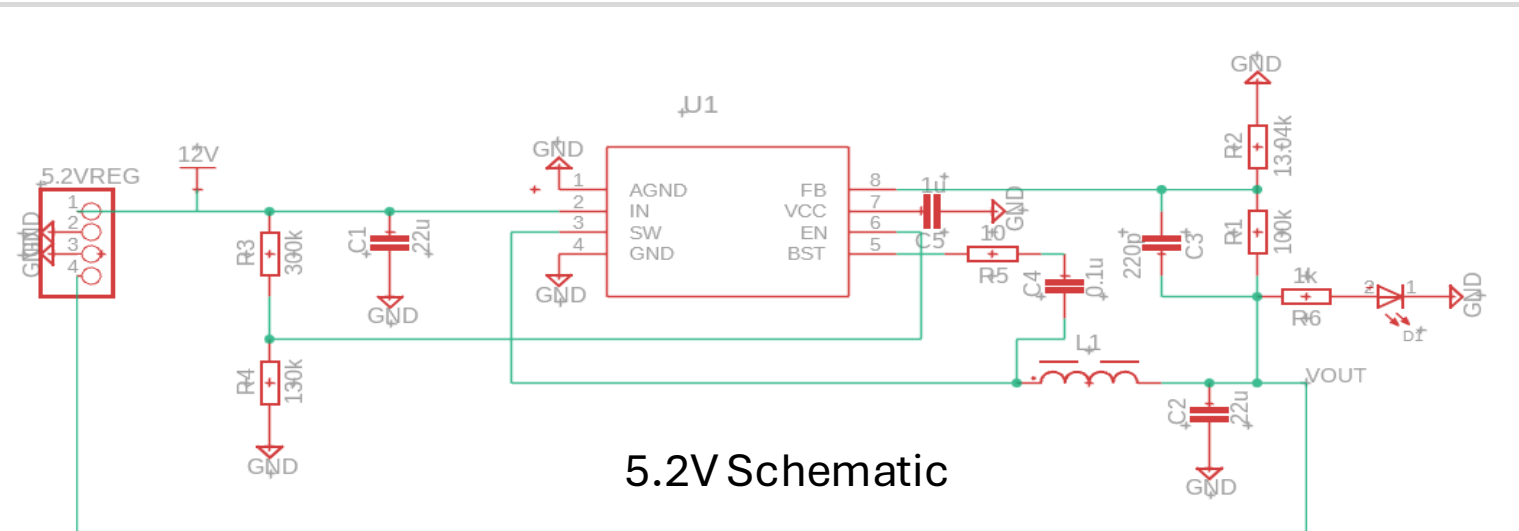
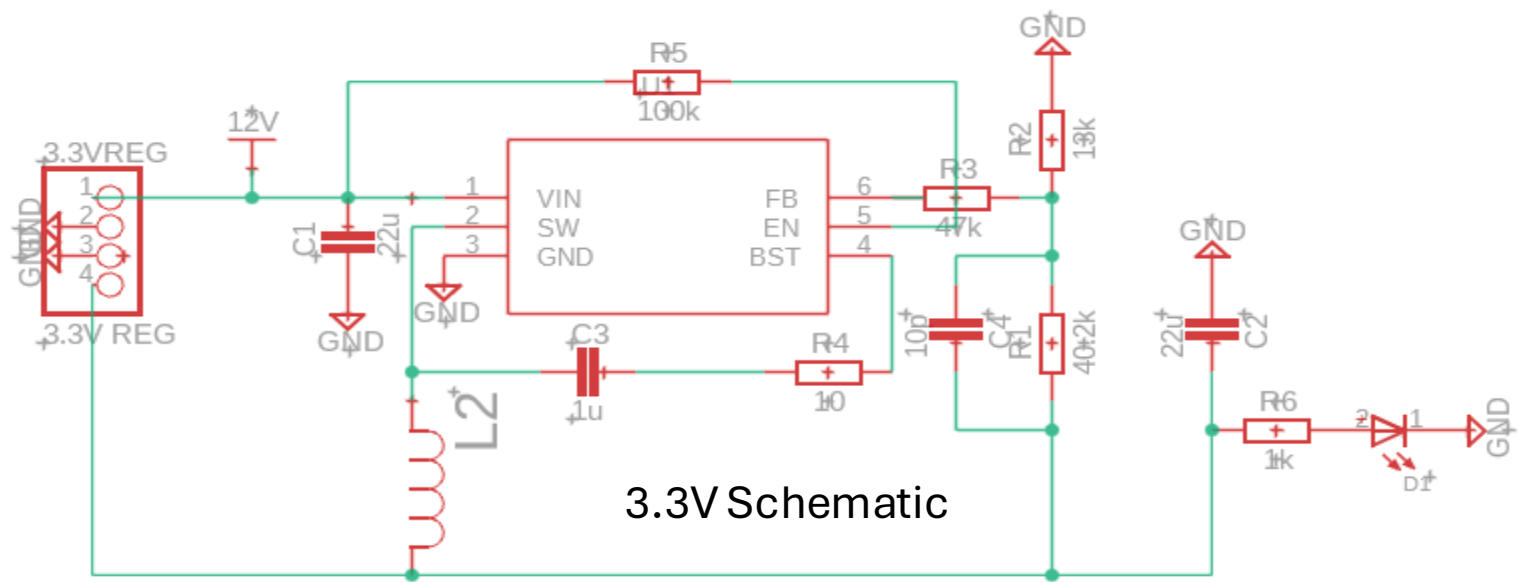


Aspect	MP1479	LM2596	MP2236C	TPS54JA20
Brand	Monolithic Power Systems	Texas Instruments	Monolithic Power Systems	Texas Instruments
Input Voltage Range	4.2V to 18V	4.5V to 40V	3.0V to 18V	2.7V to 16V
Output Voltage Range	0.8V to 10V	1.2V to 37V	0.6V to 8V	0.9V to 5.5V
Max Output Current	1A	3A	6A	12A
Switching Frequency	800kHz	150kHz	600kHz	600kHz-1MHz
Price	\$1.62	\$5.20	\$2.81	\$2.24



Jeffrey | EE

PCB Design



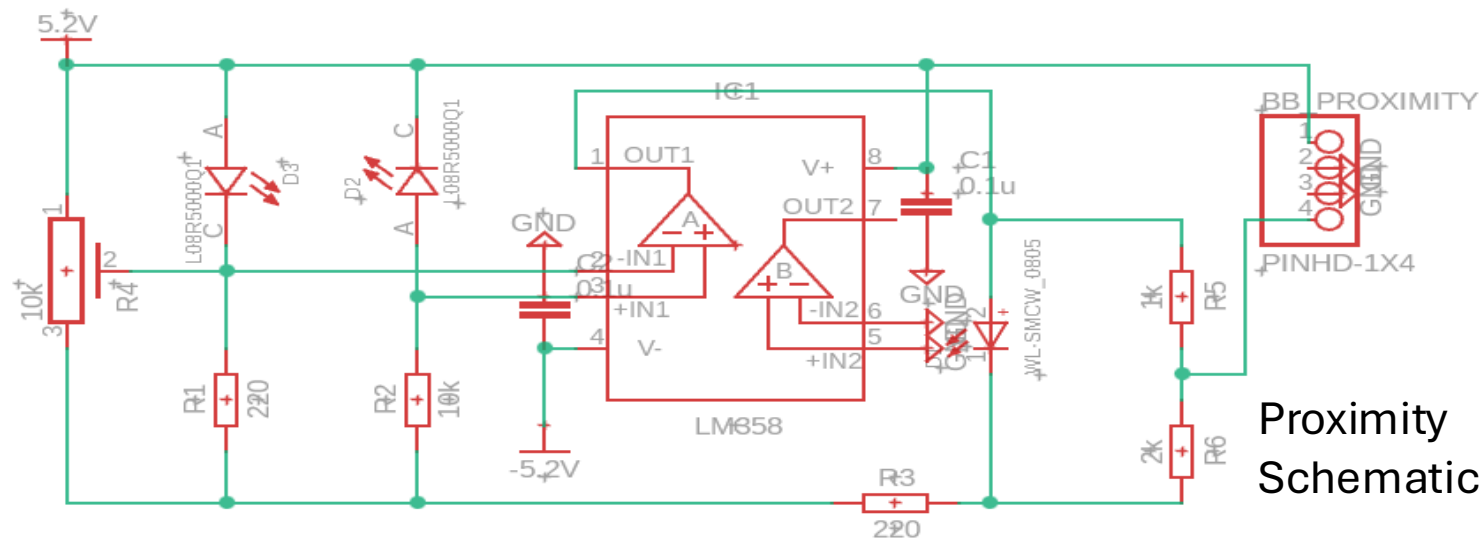
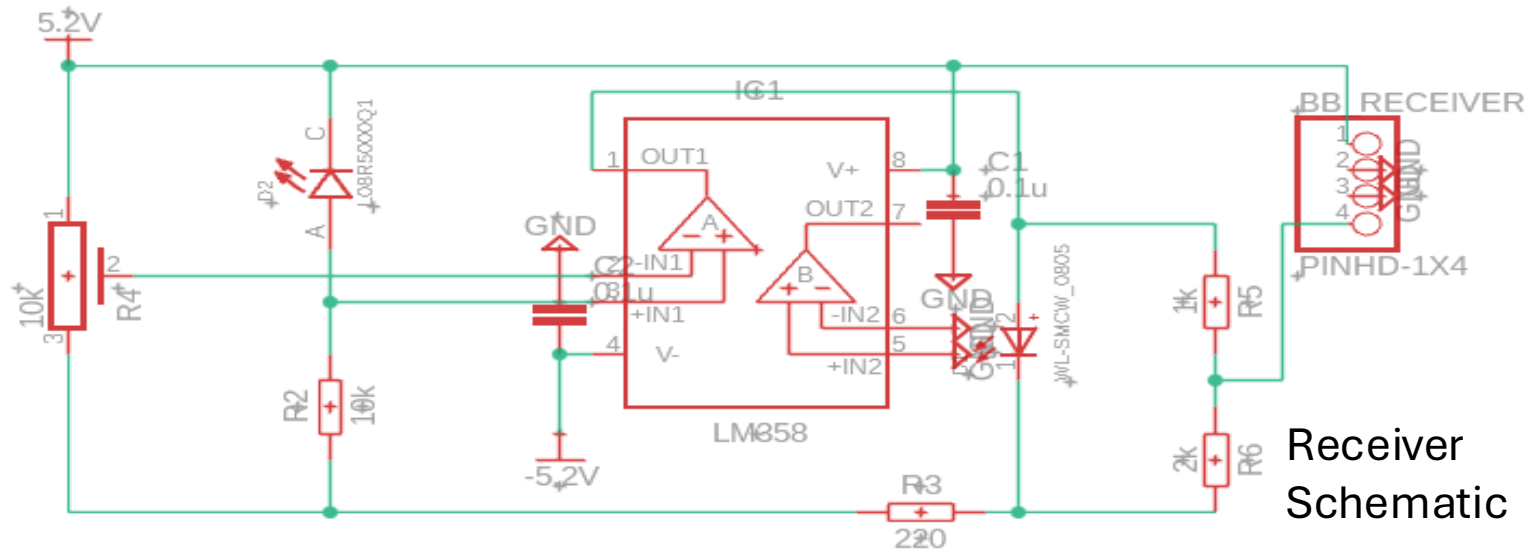
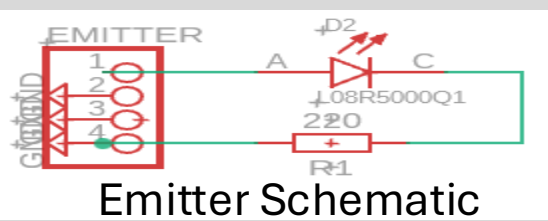
Power Boards

- 12V DC input, diverged power output
- 3.3V up to 1A Output to MSP430 and Pressure Pad Sensor
- 5.2V up to 6A Output to Raspberry Pi 5, Proximity Sensor and Break Beam Receiver Sensor
- Separation of power assists with troubleshooting and repairs
- Power LED Indicator



Jeffrey | EE

PCB Design



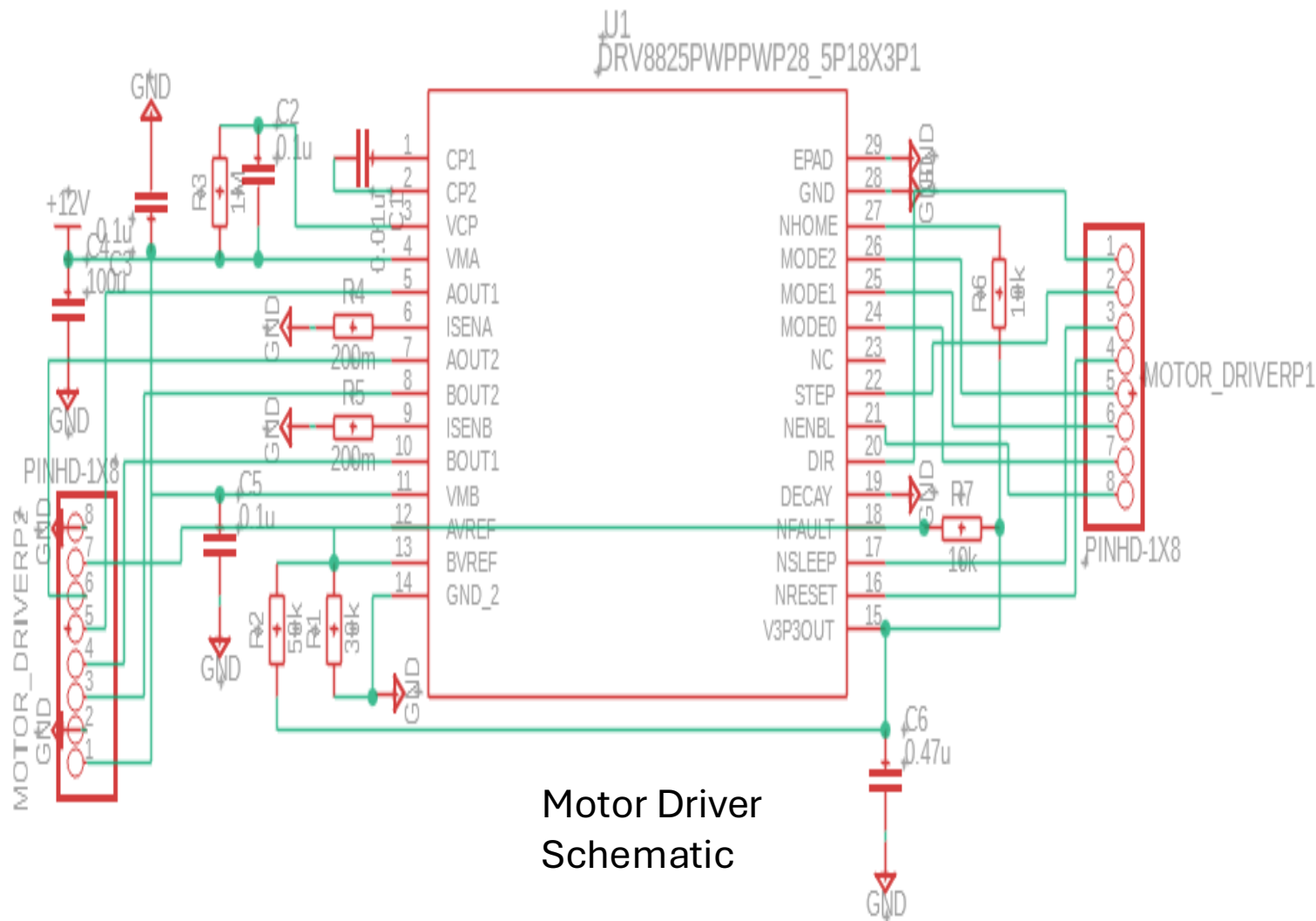
Optical Boards: Proximity, Break Beam Receiver, and Emitter Sensors

- 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



Jeffrey | EE

PCB Design



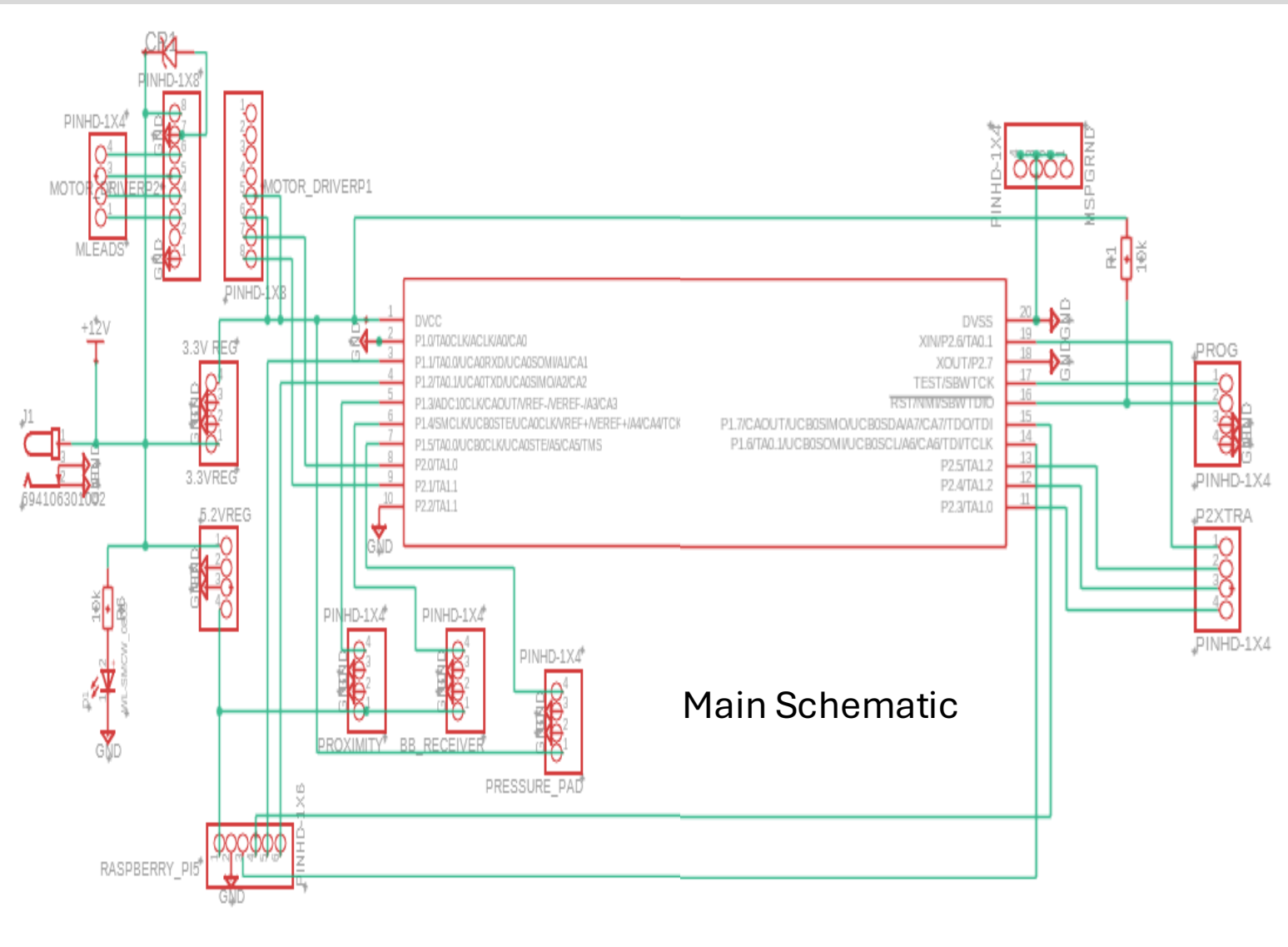
Motor Driver Board

- Two 8-pin header for plugging into Main PCB that matches breakout board for easy troubleshooting
- Dedicated pin for input power rail
- GPIO pins for communicating with the MSP430



Jeffrey | EE

PCB Design



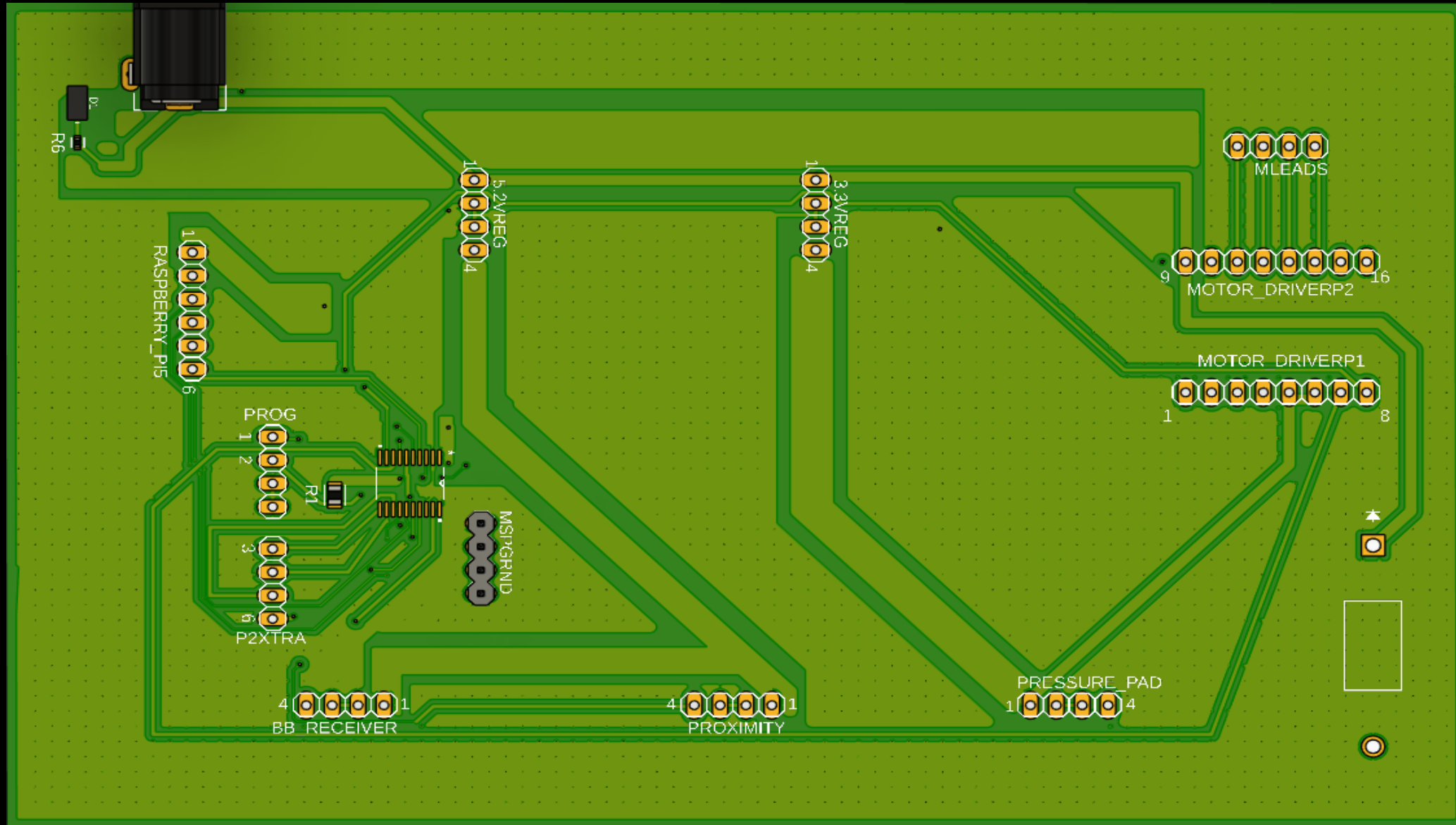
Main Board

- 120V AC Outlet adapted to 12V DC input routed to motor driver, 3.3V and 5.2V 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

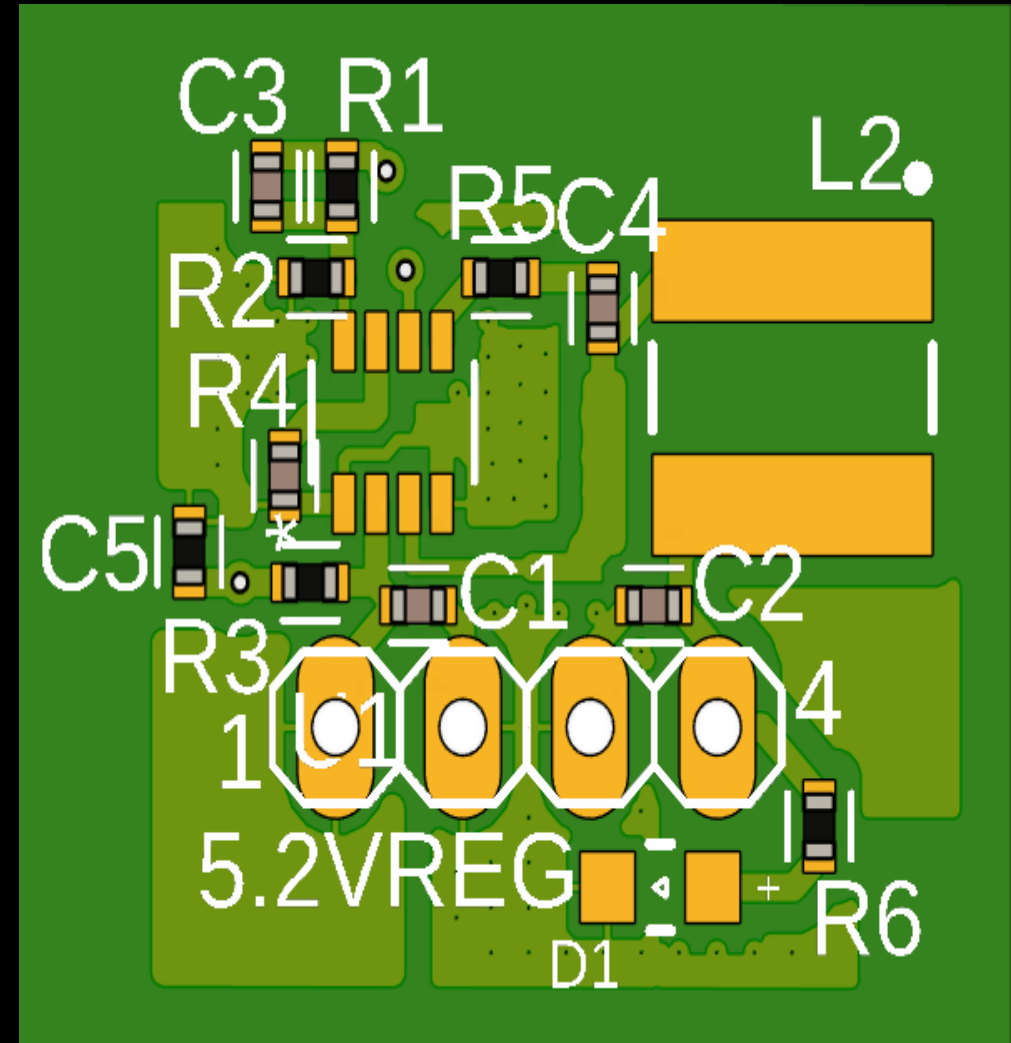
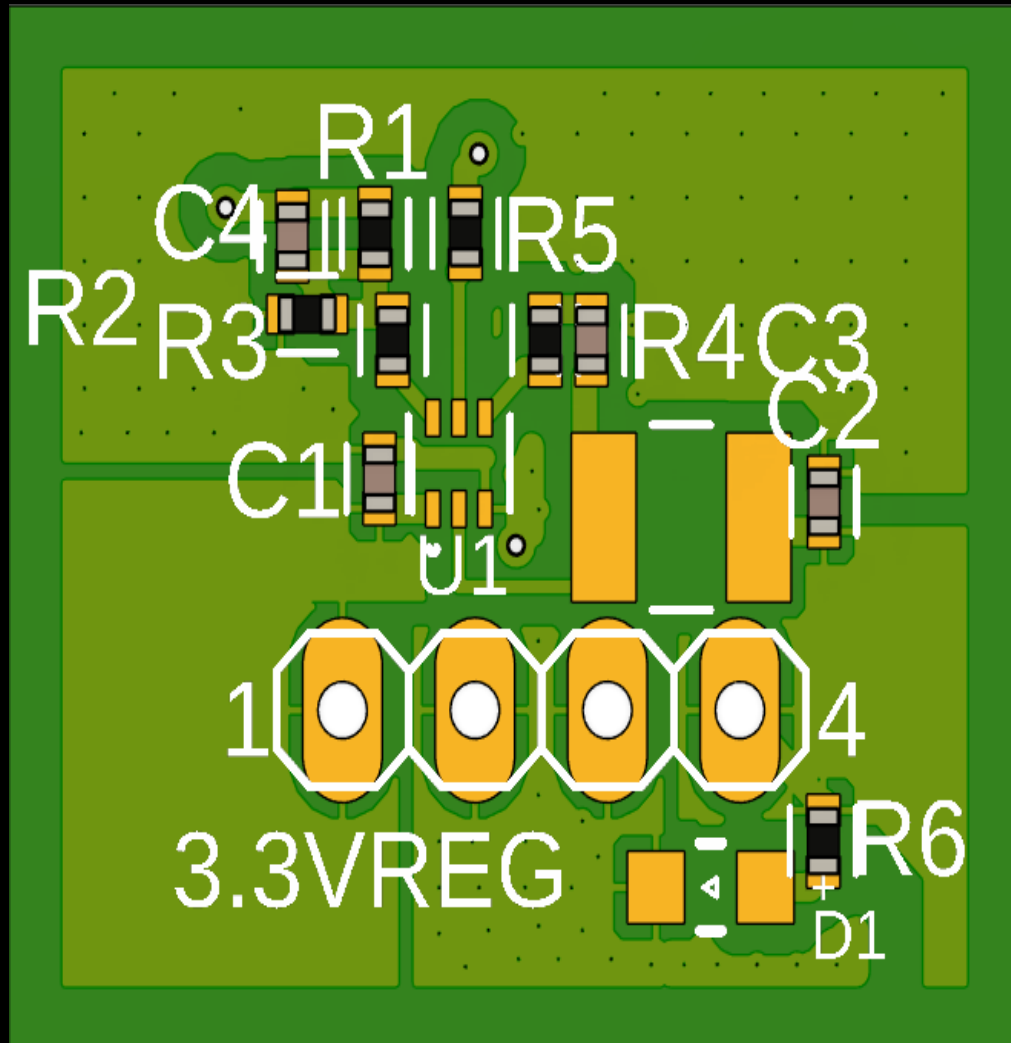


Jeffrey | EE

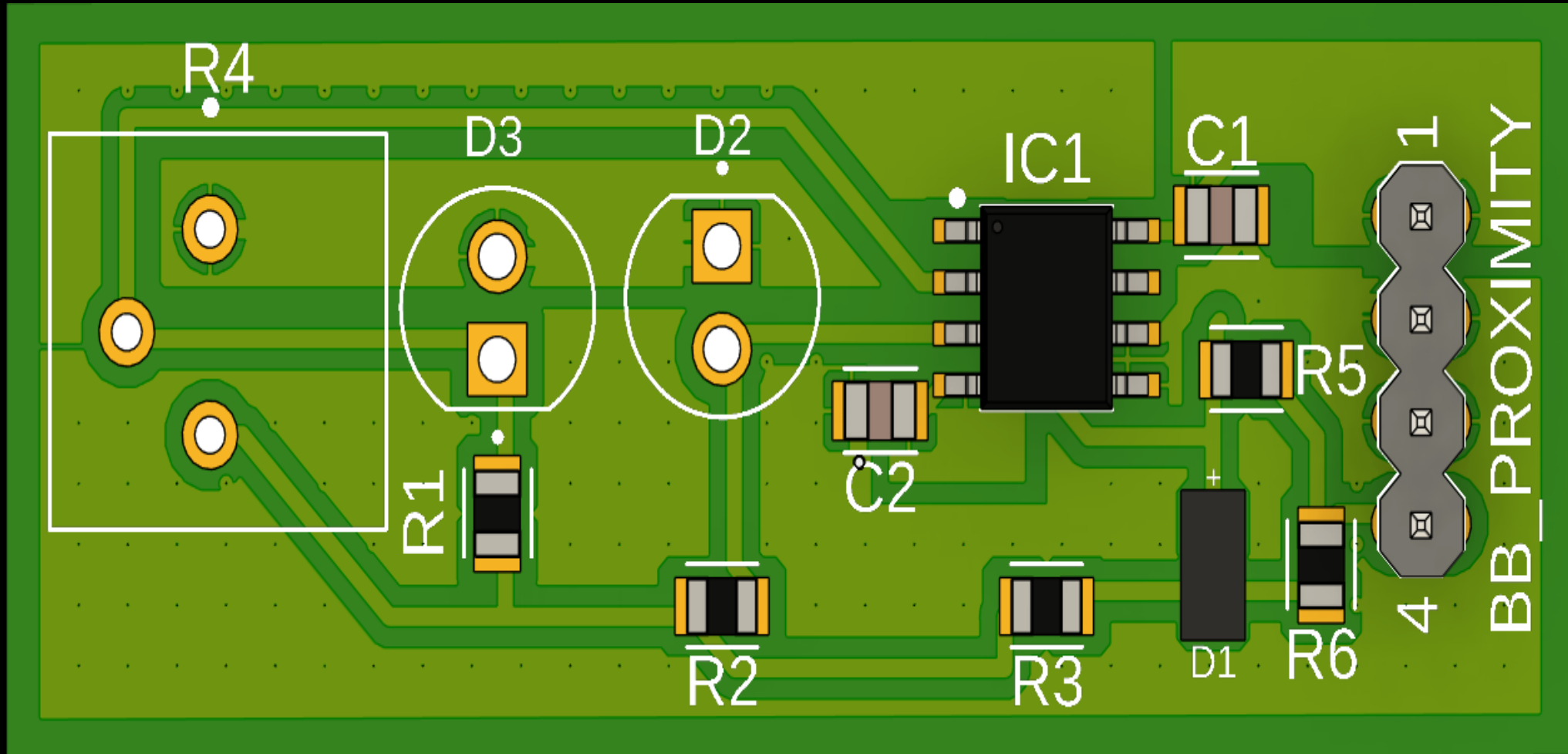
PCB Layouts – Main PCB



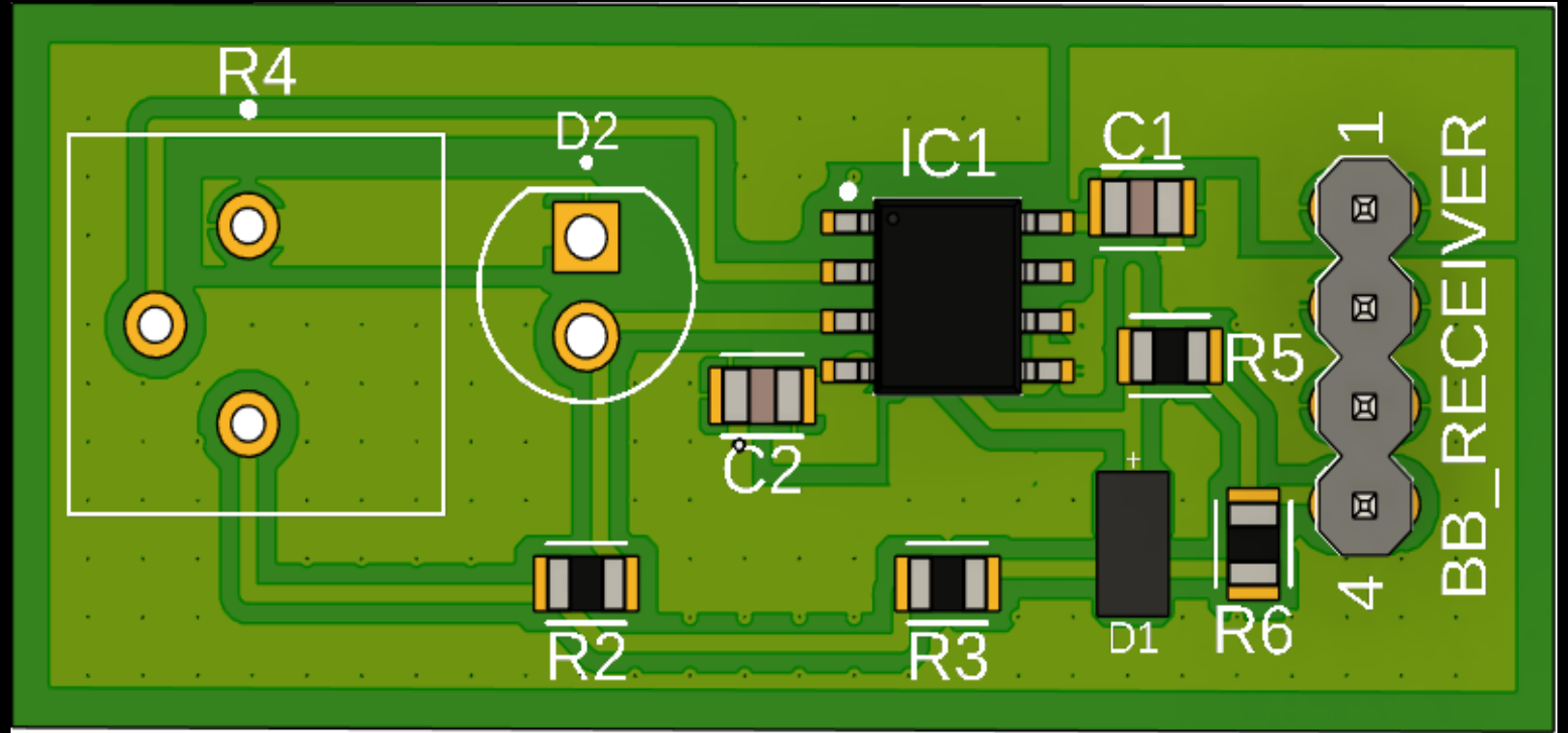
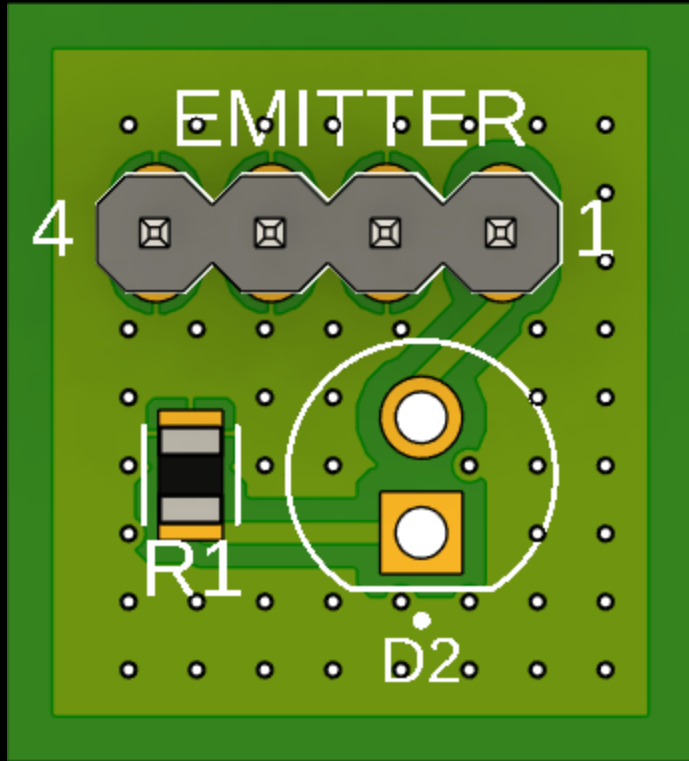
PCB Layouts – Voltage Regulators



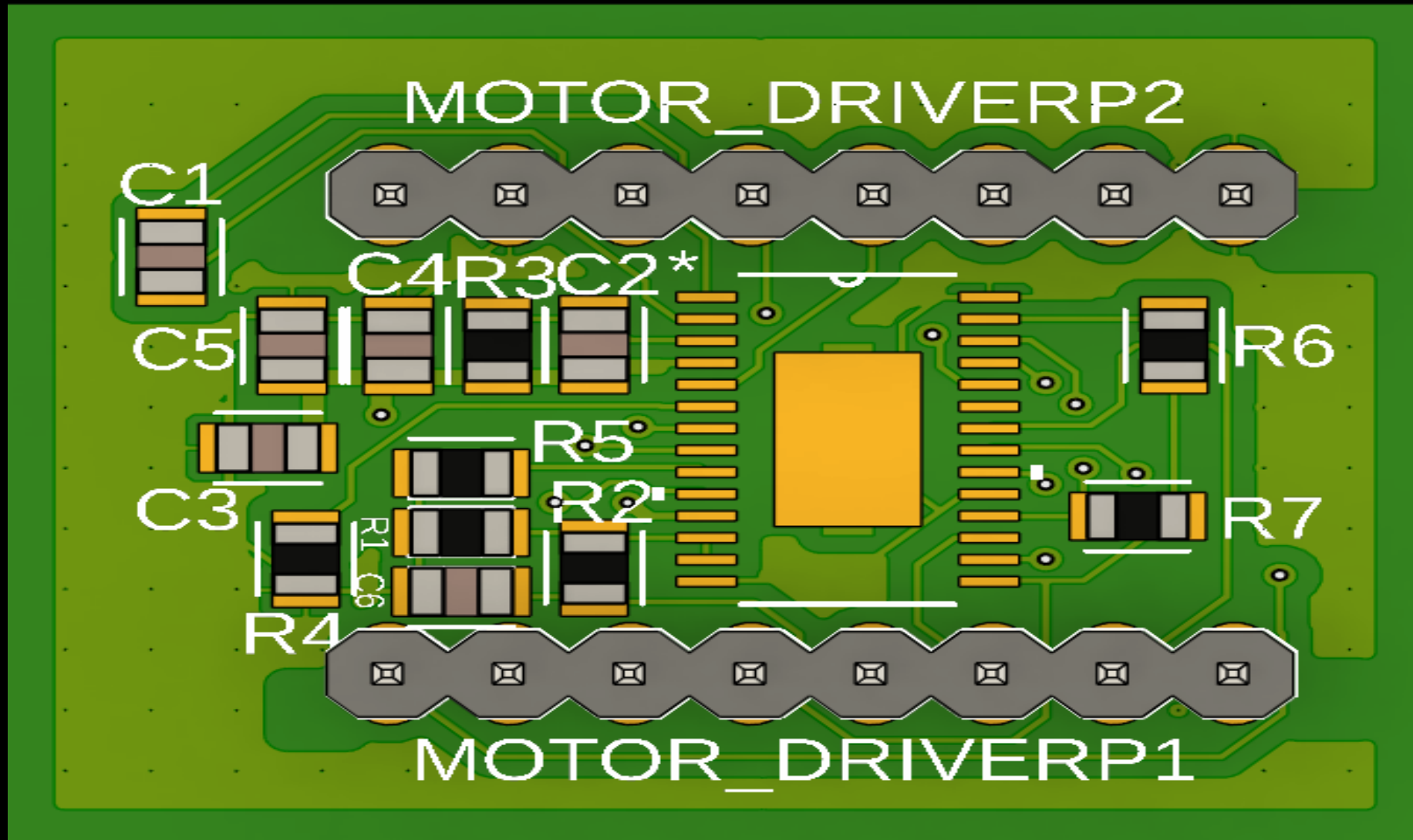
PCB Layouts – Optics Proximity Sensor



PCB Layouts – Optics Break Beam Sensor



PCB Layouts – Motor Driver



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



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YOLO Object Detection

The chosen object detection model is **YOLOv10**

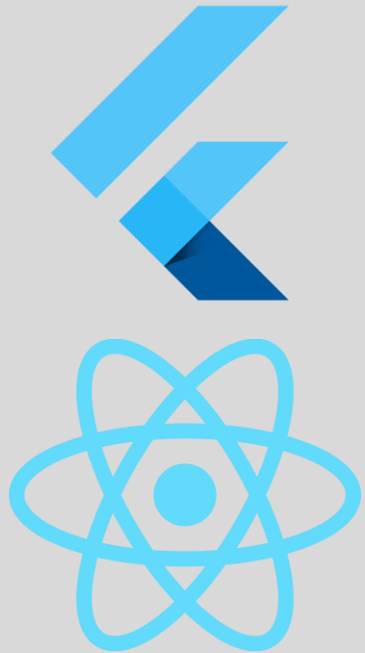
- Successfully detects cats within field-of-view with accuracy between 80% - 95%
 - Adds a bounding box and classification label around detected object
 - NoIR camera can detect objects at all times of day
- Fast and accurate, but needs further optimization
 - Currently running between 0.7 to 1.5 fps
 - Can only run nano or small versions reliably (w/o crashing)
 - Further testing with newer YOLO11 model may help solve these problems



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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



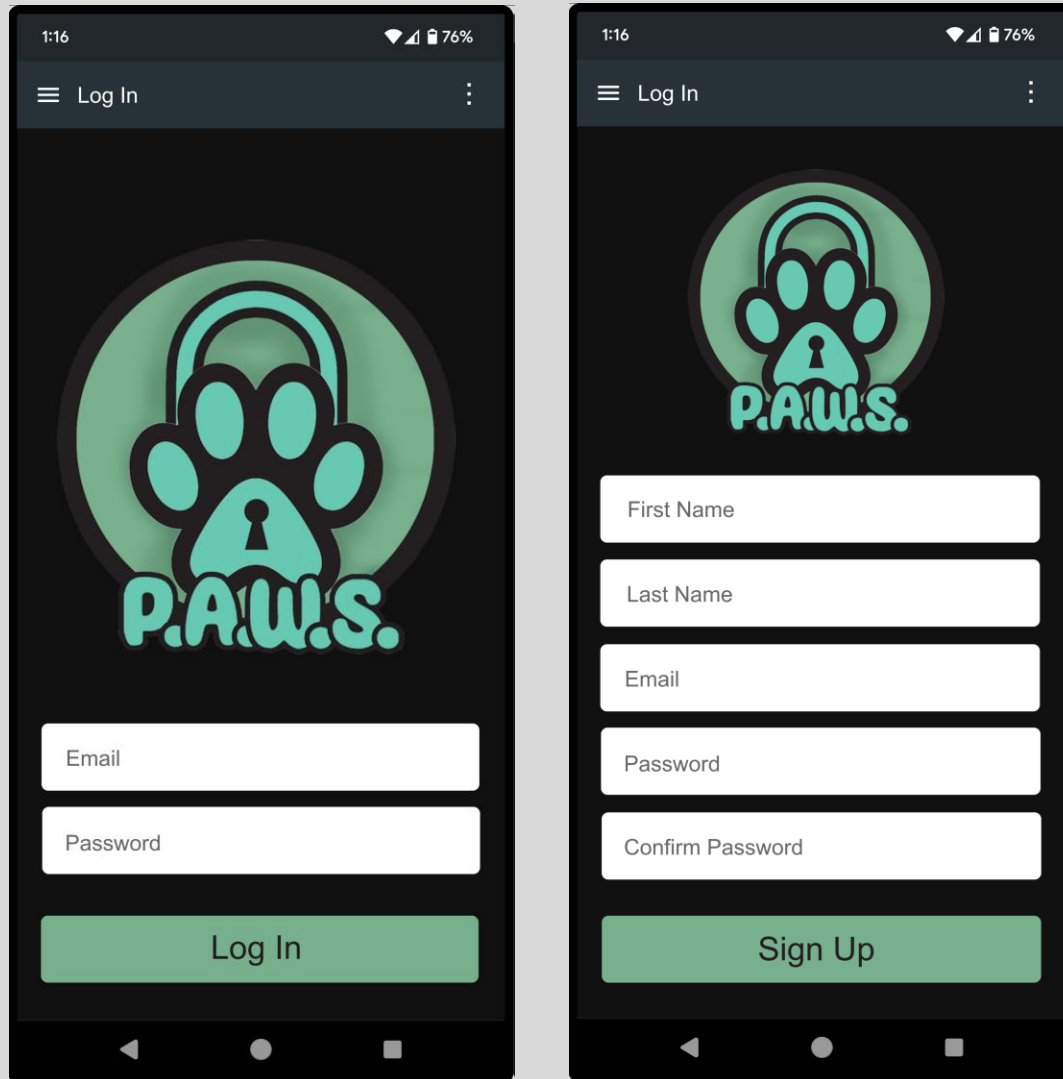
Firebase is a platform owned by Google that offers backend services for mobile and web applications

- 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



Current page design ideas are still WIP and likely to change

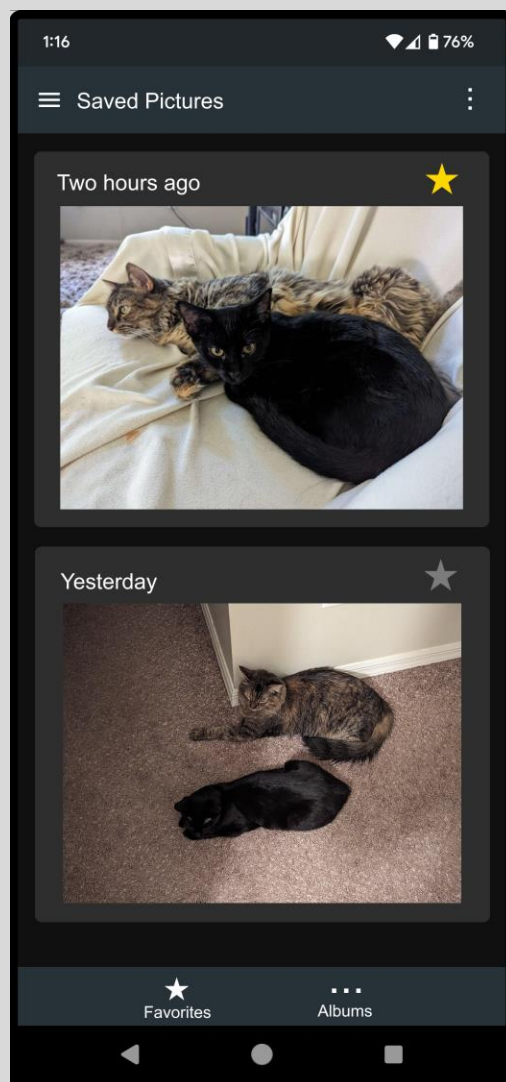
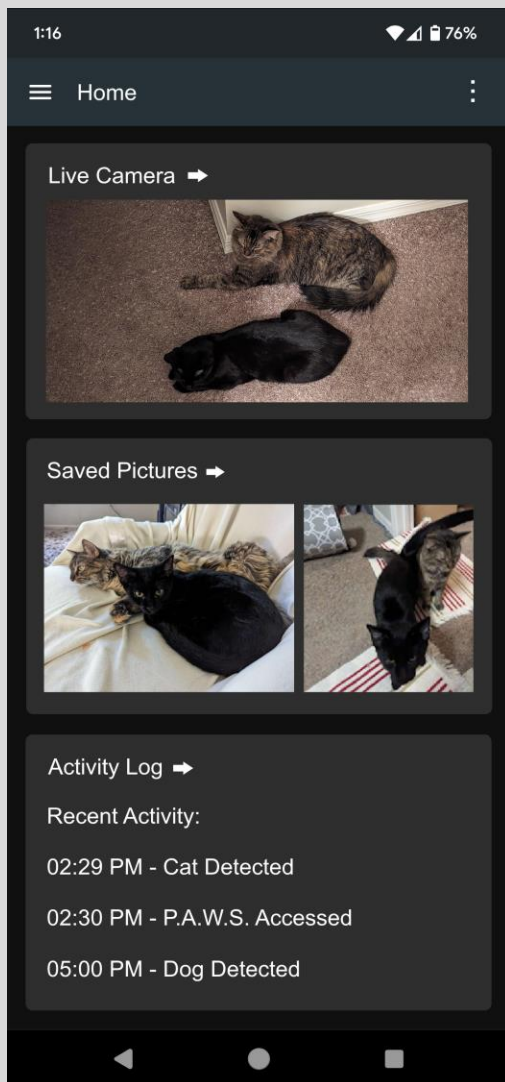
Login and Signup Pages:

- Users are asked to enter a first and last name, email, and password
- Email and password will be the unique identifiers for logging in
- Users will be able to change their first/last name and password inside the app
- Firebase Authentication can easily handle signups and storing hashed user credentials into a database



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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

Saved Pictures Page:

- Gallery of images sent from the Pi whenever important actions are triggered
- Users can favorite, sort into custom albums, or delete images

Activity Log Page:

- Simple text page showing recent P.A.W.S. enclosure activity
- Examples include cat / dog detection or motorized door openings



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System Testing/Progress

Physical Enclosure Build

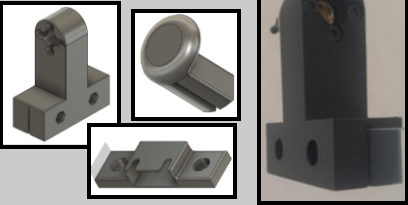
Physical enclosure built:



Rail system built:

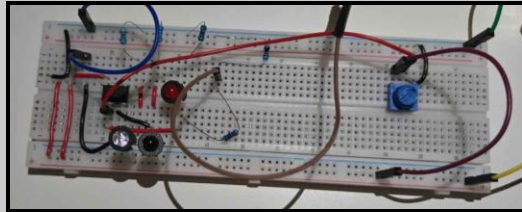


Door clamp designed/3D printed, microswitch housing and pusher designed/3D printed

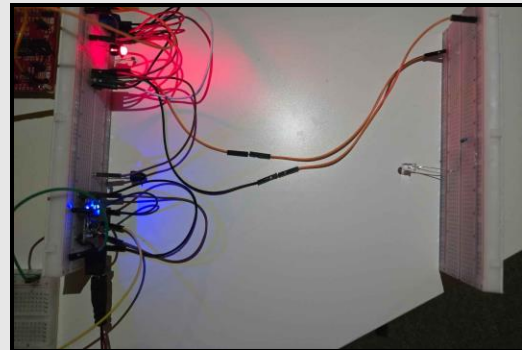


Optical Sensors

Circuit for proximity sensor:

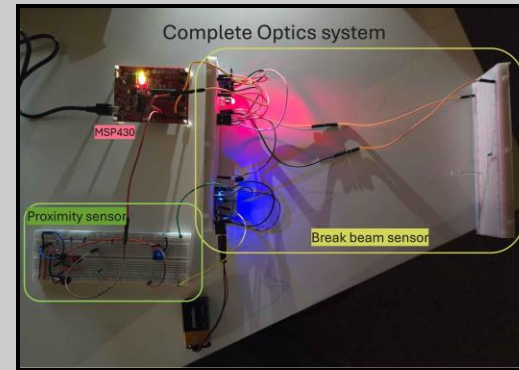


Circuit for break beam sensor:

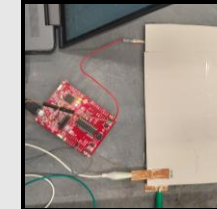


MSP430 Programming

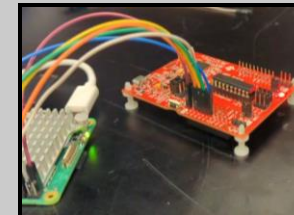
Software for both optical sensors:



Software for pressure pad sensor:



Software for UART communication with Raspberry Pi:

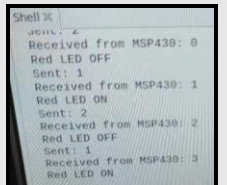


Raspberry Pi Programming

Software for LLM object identification with Pi camera module



Software for UART communication with MSP430



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
LCD display	\$35.99 (1)	-
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

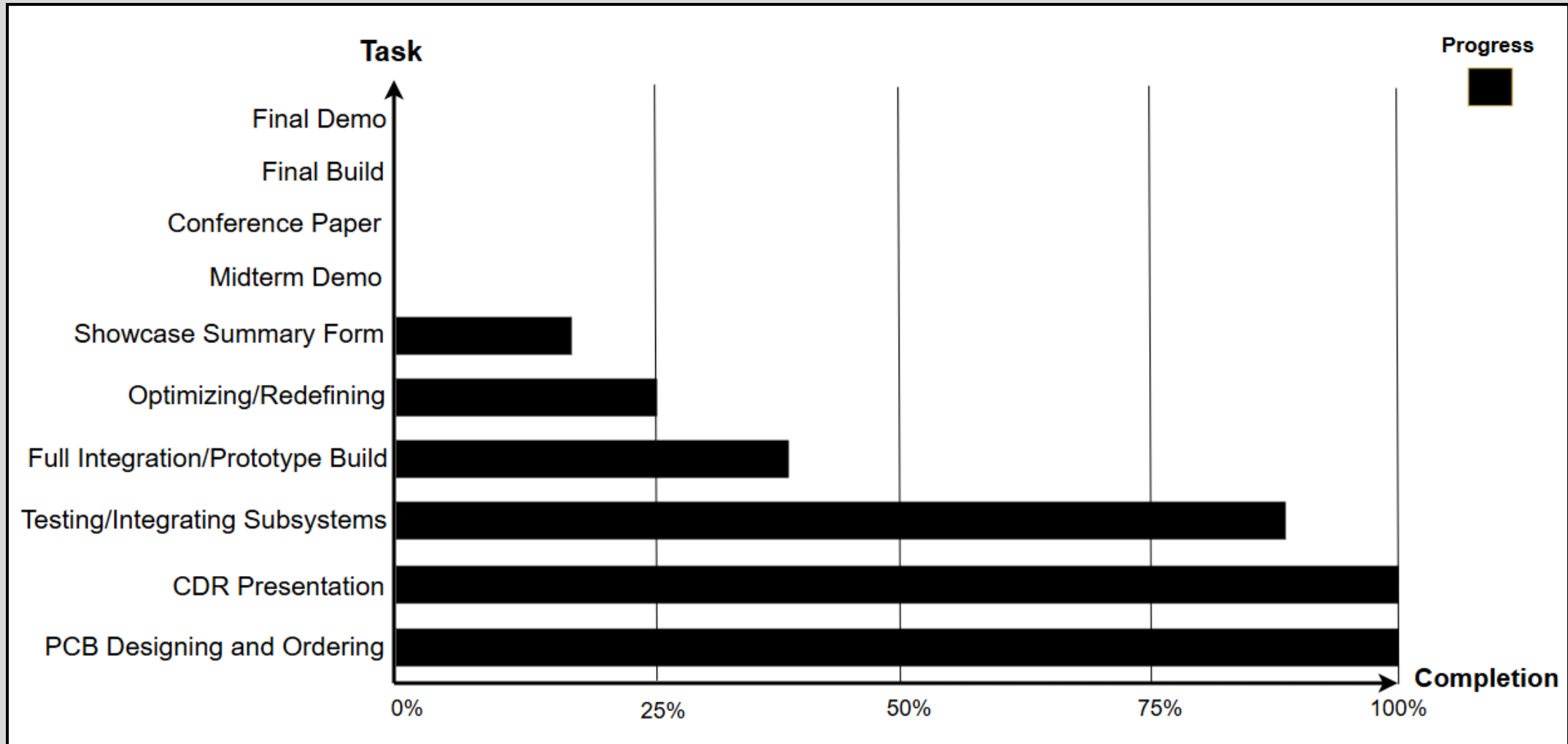


Work distribution

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



Progress and Plan for Completion



Thank you for listening!