Sit & Chow – Smart Training Dog Feeder

Critical Design Review

Group 25

Advisor:
Dr. Saleem Sahawneh – ECE

Review Committee:
Dr. Tong Wu – ECE
Dr. Shahana Ibrahim – ECE
Dr. Truong Nghiem – ECE

Group 25 Members

Andres Arzola
Computer Engineering

Andrew Balmes
Electrical Engineering

Natalie Nguyen
Electrical Engineering

Maria Tran
Computer Engineering

Motivation and Background

- Many pet owners do not have the time to feed or train their dog.
- Automatic feeders offer a convenient solution to feeding your pet on time.
- There are many newer automatic feeders with cameras and other modifications, however, none offer any aid in the dog's behavior towards food.
- We want to create a system that combines automated feeding and helps train their behavior.

Goals

1. Provide a reliable, automated feeding solution for dogs.
2. Reinforce obedience training by requiring a dog to sit before eating.
3. Allow for owners to conveniently manage feeding times and portions through a mobile app.
4. Monitor system status and system reliability.
5. Allow for owners to check in with their dog at any point of the day through the mobile app and camera.

Objectives

1. Develop a food dispensing system that operates on a timer.
2. Incorporate a camera to detect a dog's posture.
3. Design a mobile app for scheduling feeding times, adjusts portion sizes, logs feeding history.
4. Include sensors to check food supply level and how far a dog is from the system.
5. Include a speaker on the system and add the feature on the app.

Engineering Specifications

Aspect	Specifications
Food Storage Capacity	Maximum 5 kilograms
Dispensing Time	Under 30 seconds
Portion Accuracy	±5 grams
Depth Sensing range	Up to 2 feet
Sound Output	65-70 dB
Camera FPS	10-30 FPS
Posture Detection Accuracy	At least 90%
Feeding Schedule Accuracy	Within 3 minutes
Mobile App Features	Creating and editing feeding schedules, feeding override, logs of past, feeding schedules, notifications, and user authentication
Data Logging Retention	Minimum 30 days

Hardware Comparisons

ESP32-S3

Why We Chose The ESP32-S3

- The ESP32-S3 has built-in camera support for the OV2640 and OV5640, allowing for a simpler integration.
- **More memory** than the ESP32-CAM and ESP32-WROOM, which is necessary for camera frame buffering.
- **Improved performance** over the ESP32-CAM, and more flexible and suitable for handling simultaneous camera and sensor processing.
- Built in Wifi/Bluetooth allows for a reliable connection with the mobile app.
- Overall, the ESP32-S3 offered the best performance and flexibility for our system.

	ESP32-WROOM-32	ESP32-CAM	ESP32-S3
CPU Architecture	Dual-core Tensilica LX6 @ 240 MHz	Dual-core Tensilica LX6 @ 240 MHz	Dual-core Tensilica LX7 @ 240 MHz (improved performance and efficiency)
Camera Support	None (no DVP/CSI interface)	Built-in OV2640 2MP camera (via GPIO)	Native DVP camera interface (supports OV2640, OV5640)
USB Inferface	Requires external UART adapter	Requires FTDI programmer	Native USB OTG — direct flashing and debugging
Peripheral Interfacees	SPI, I²C, UART, I²S, PWM, ADC/DAC, GPIO	SPI, I²C, UART (limited GPIO due to camera/SD use)	SPI, I²C, UART, I²S, CAN, PWM, ADC/DAC, GPIO (expanded pin matrix)
GPIO Availability	30+ usable GPIOs	6–7 available after camera/SD use	30+ usable GPIOs (depending on module configuration)
Wireless performance	Wi-Fi 2.4 GHz + BLE 4.2	Wi-Fi 2.4 GHz + BLE 4.2	Wi-Fi 2.4 GHz + BLE 5.0 (improved throughput)
Ease of Programming	Easy; widely supported by Arduino and ESP-IDF	Moderate; requires UART flashing and external power stability	Easy; native USB simplifies programming and debugging
Cost	$5–$8	$7–$10	~$9

OV5640 Camera

Desired Camera Features/Qualities

- **Resolution:** The resolution of the camera that we picked out had to have a good enough resolution to be able to see when the dog has entered the camera's view.
- **Field of View:** The Camera's FOV had to be wide enough to pick up the dog if it were to be located on one of the sides of the dog feeder.
- **Low-Light Sensitivity:** Picking out a camera that could effectively pick up if the dog was present during poor lighting situations.
- **Cost**
- **Integration into our MCU**

OV5640

- The OV560 contains a resolution of 2592x1944 pixels. Allowing for reliable accuracy in the detection of the dog and its posture.
- Proficient when operating under varying lighting situations.
- Contains an interface that allows it to work cleanly with the ESP32-S3.

	OV2640	OV5640	Realtek AMB82
Resolution	2 MP (1600x1200)	5 MP (2592x1944)	2 MP (1920x1080)
Frame Rate	15-30 Fps	30 fps / 1080p	30 fps /1080p
Field Of View	Modest	Wide	Wide
Low-Light Sensitivity	Decent but needs good lighting	Good Low-Light Performance	Best
Cost	Cheap	Moderate	High
Size	Around 25 x 24 mm	30 x 28 mm	40 x 30 mm
Ecosystem Support	Large Ecosystem	Good Ecosystem	Less support than the other two cameras

Motor & Motor Driver

Motor	Pros	Cons	Notes
Stepper (NEMA-17)	Open-loop precision, easy microstepping, stall detect with modern drivers	Higher current draw and heat when holding, more expensive	Best choice for auger metering
DC + gearbox	Low cost, efficient	Requires encoder or feedback loop for precision	Suitable for timed dispensing systems
RC Servo	Simple control set up	Limited torque and shorter lifespan	Ideal for flap gates only

Feature	A4988	DRV8825	TMC2209
VMOT Range	8–35V.	8.2–45V.	Up to ~28V.
Max Current (typical use)	~1–2A/phase with cooling.	~1.5–2.2A/phase with cooling.	2A RMS, 2.8A peak/phase.
Max Microstepping	1/16 step.	1/32 step.	1/256 (via interpolation).
Noise Level	High (audible whine).	High–moderate.	Very low (StealthChop2).
Special Features	Basic protections.	Strong current regulation, protections.	StealthChop2, SpreadCycle, StallGuard4, CoolStep.
Suitability for Dog Feeder	OK for budget prototypes.	Overkill voltage, too noisy.	Best match: quiet, smart, enough current.

Speaker

Feature	1W 8Ω Speaker	5W 8Ω Speaker	3W 4Ω Full-range Speaker
Speaker Type	A standard speaker, possibly optimized for a specific, narrower range of frequencies. The sound could be less balanced than the full-range option.	A standard speaker, potentially with a narrower frequency range.	A single driver designed to produce a wide range of frequencies, from low to high. This is ideal for voice playback and alert tones.
Impedance (Resistance)	Higher impedance (8Ω)	Higher impedance (8Ω)	Lower impedance (4Ω)
Wattage (Power Handling)	Lower wattage (1W)	While capable of handling more power (5W)	The 3W
Loudness (Sensitivity)	Less efficient and likely quieter than the 4Ω option for the same input voltage.	Less efficient than the 4Ω option.	A 4 Ω speaker can be louder than 8 Ω speaker
Pros	Low power rating means very modest current or drive required. 8Ω is a common safe impedance for small amplifiers (the microcontroller audio driver likely can handle it). Lower cost, smaller size.	Higher power handling given more headroom for louder notifications, which may help in presence of ambient noise. Still 8Ω, which is compatible with many drivers.	4 Ω impedance draw more current at a given voltage, meaning more available acoustic output for the same voltage – useful in low-voltage system. A full-range speaker covers the tone/frequency band of interest (the dispense chime) without needing separate tweeter/woofer 3W rating is the modest but sufficient for a small feeder environment.

- We decided **3W 4Ω Speaker** is a best balance for what we need: moderate power (3W) suitable for embedded drive, lower impedance (4Ω) to use voltage efficiently, and full range for nice tone. The other options either under-power (1W) or over-spec (5W) potentially wasting cost and driving complexity.

Amplifier

Features	Class A	Class AB	Class D
Efficiency	~25% (very low).	~50-70% (moderate).	>90% (very high).
Heat Dissipation	High, requires a large heat sink.	Moderate.	Low, minimal or no heat sink needed.
Fidelity	Very high, low distortion.	High, with minimal crossover distortion.	High, modern designs offer excellent audio quality.
Advantage	Excellent linearity and low distortion (very little crossover distortion) because the device is always on and in its linear region. Good for high-fidelity audio (audiophile territory).	Good compromise: lower distortion than Class B, better efficiency than Class A. Widely used in home audio stereo amplifiers.	Very high efficiency because the devices are either fully on or off (hence minimal wasted power as heat) Compact size, lower heat sink requirement, good for embedded systems (battery or low-power).

Feature	MAX98357A	PAM8403	PAM8302
Input Type	I²S Digital	Analog	Analog / PWM
Channels	Mono	Stereo (2 ch)	Mono
Noise & Quality	Clean digital path. Low hiss. Great clarity.	Acceptable for simple tones. Noise depends on analog path.	Can pick up noise. Dependent on analog cleanliness.
Power Output (5V)	~3.2W into 4Ω	~3W ×2 into 4Ω	~2.5W into 4Ω
MCU Compatibility	Native support on ESP32 & similar MCUs	Works with PWM/DAC	Works with PWM or simple DAC
Ease of Use	Moderate. Needs I²S setup but straightforward.	Easy. Many ready boards.	Very easy. Minimal configuration.

- The MAX98357A offers superior audio quality and immunity to noise by accepting a digital audio stream directly, which is a major advantage for a reliable, multi-featured project like a pet feeder.

Button

Feature	Tactile Switch	Metal Push Button
Use for	PCB mounted	Panel mounted
Durability	Moderate. Can be damaged by heavy or repeated pressure.	Very high. Designed to withstand heavy use and resist vandalism
Tactile Feedback	Clear, audible "click."	Distinct, high-quality "push" feel.
Aesthetics	Utilitarian. Not typically visible to the end user.	Premium, industrial appearance.
Mounting	Requires soldering to a specific footprint on the PCB.	Requires a circular cutout in the enclosure and a fastening nut.
Cost	Very low.	Moderate to high, depending on material and features.
User Experience	Best for internal testing or user interfaces where the button is covered.	Provides a robust, confident interaction for the end user.

Feature	Elegoo-Style 6×6×6 mm Tact	TS02-66-70-BK-160-LCR-D	Adafruit 6 mm Tact
Mounting	Through-hole, breadboard-friendly	Through-hole, long crimped pins	Through-hole, breadboard-friendly
Contact type	SPST-NO, momentary (typical)	SPST-NO, OFF-(ON)	SPST-NO, momentary
Electrical life	Vendor-dependent, ~50–100k cycles typical	80,000 cycles	High (B3F family is typically 1M mechanical cycles)
ECAD models	Usually generic 6×6 footprint	Vendor ECAD & 3D models available	EAGLE lib, Omron B3F-10xx footprint
Cost / availability	Extremely cheap, widely available in kits	Slightly higher, but still low for OEM	Low–medium, sold in hobby packs
Breadboard prototyping	Excellent	Less convenient (long crimped pins, but works)	Excellent

SERIES: MPB06 | **DESCRIPTION:** MINI PUSH BUTTON SWITCH

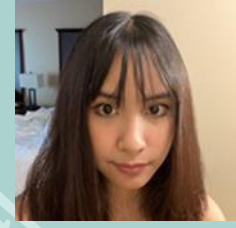
FEATURES
- single pole
- surface mount
- tape and reel

- Back up plan for feeding if product doesn’t work
- Easier for owners
- Need to change for surface mounting

Sensing Storage Capacity

Feature	Load cell Sensor	Infrared Sensor (IR)	Capacitive Sensor	Ultrasonic Sensor
Accuracy	Very high, ideal for precision weight measurements. Must be properly calibrated for the specific load	Fair for simple presence detection, but can be unreliable with different food colors, textures, or ambient light.	Good for level sensing in a controlled environment but can be affected by food density and moisture.	Good for distance measurement and non-contact level sensing
Environment Factors	Mostly immune, especially with hermetic sealing. Sensitive to vibrations if measuring minor	Prone to interference from dust, direct sunlight, and changing ambient light.	Sensitive to temperature, humidity and material build-up on the sensor.	Can be affected by extreme temperature changes, but generally reliable in typical home environments.
Pros	Measures actual weight for precise portion control; Can be very accurate and reliable for batching.	Inexpensive and easy to implement.	Low cost, durable, and suitable for non-conductive materials.	Non-contact method is hygienic and not affected by food type or color; Affordable, widely available, and simple to interface with microcontrollers.

Feature	RCWL-1601	JSN-SR04T	A02YYUW
Supply Voltage & Logic	3.0–5.0 V, logic = supply	5 V supply (some variants 3.3 V logic tolerant)	3.3–5 V supply (UART output)
Range (Typical)	~2–400 cm	~25–600 cm	~6–750 cm
Key Features	HC-SR04 protocol but works at 3.3 V or 5 V	Waterproof transducer on cable	Waterproof ultrasonic with digital UART output
Pros	Direct ESP32 compatibility; no level shifting; low cost; compact	Very rugged; moisture/dust resistant; long range	Waterproof; noise-filtered digital output; good accuracy
Cons	Not waterproof; dust may degrade accuracy over time	More expensive; mounting more complex; cable + puck footprint	More expensive; UART parsing required; slower update rate
Suitability for Dog Feeder	Best choice for indoor dog feeder; ideal electrical compatibility	Excellent for outdoor or washable feeders; overkill for indoor use	Good for industrial feeders; more complex than needed



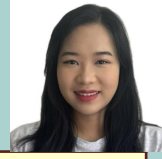
Depth Sensor

- High Distance Accuracy: cm-level precision, great for verifying that the dog is within feeding range.
- Digital I2C interface: clean integration with the ESP32-S3. No need for pulse timing measurements like ultrasonic sensors.
- Quiet: ToF sensor does not emit any audible sounds that may disturb the dog like ultrasonic waves.
- Fur: most sensors are sensitive to reflections and light. The ToF sensor is sensitive to sunlight, but the system must be operated indoors.

Sensor	Advantages	Disadvantages
Ultrasonic Sensor	Cheap Simple to integrate with GPIO	Sensitive to noise reflections like the bowl or fur Dogs can potentially hear the wave noise
Infrared Sensor (IR)	Compact and low power Good for short range detection	Sensitive to ambient light Dark fur color can reflect poorly
Time-of-Flight Sensor (ToF)	Works in dark or light environments Easy to integrate with I2C connection	Narrow FOV (~15–27°) Sensitive to sunlight
mmWave	Unaffected by light and fur color Can detect subtle motions	High power High cost More complex data parsing

Category	VL6180X	VL53L0X	VL53L5CX	TMF8701
Range	0 – 200mm	20 – 2000mm	0.05 – 4m	2cm – 1m
Accuracy	±5mm	±25mm	±15mm	±20mm
Features	Great for short distances Too short for feeder	Slightly reduced accuracy be yond 1m Stable up to 2m; Low power	Higher cost and power Strong ambient light immunity	Extremely small; Low power Less accurat e with dark fur
Cost	$7 – 9	$7 – 10	$25 – 30	$10 – 13

Power Management – Power Supply Type

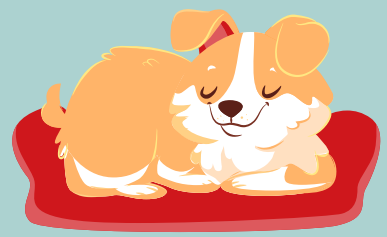


Power Supply	Advantages	Disadvantages
USB Power Banks	Portable, lightweight, rechargeable. Built-in protection: overcurrent, short-circuit, thermal. Very clean 5 V output, often low ripple. Widely available at low cost.	Auto-shutoff under low-load conditions (<50–100 mA). Cannot naturally output 9–12 V without boosters. Capacity degrades with age and temperature. Many units cannot simultaneously charge and discharge.
Bench Power Supplies	Highly accurate voltage regulation. Adjustable current limiting prevents component damage. Ideal for debugging, prototyping, and electrical characterization.	Expensive compared to consumer power sources. Bulky and not portable. Not suitable as a final embedded power solution.
Wall Adapters (AC-DC adapters)	Reliable, continuous 24/7 power. Electrically isolated for safety. Available in many voltage/current ratings. Perfect for stationary appliances.	Requires access to a wall outlet. System loses power during outages unless battery backup is added. Cheap adapters may cause electromagnetic noise.
Battery Packs	No auto-shutoff issues (unlike USB banks). Flexible voltage design (1.2 V–12 V+). Inexpensive and safe. Excellent for backup power.	Heavy and bulky. Voltage decreases as cells discharge. Need periodic replacement or charging.
Switching Power Supplies (SMPS)	Very efficient (>85–95%). Minimal heat generation. Supports high input voltage ranges. Available as ICs or off-the-shelf modules.	Switching noise and EMI. Layout must follow strict rules. Requires additional components (inductor, diode, capacitors).
Solar Panels	Renewable energy source. Ideal for remote or outdoor project. Reduces dependency on AC mains.	Unusable indoors or at night. Requires charge controller. Needs a battery to stabilize voltage. Larger physical footprint.

Power Management – Wall Adapter

Feature	12V Wall-Mount Adapter	USB-C PD Charger + PD Sink	Desktop Brick
Output Type	Fixed 12 V DC	Negotiable (5–20 V) via PD protocol	Fixed 12 V DC
Complexity on PCB	Very low (just barrel jack & filtering)	High: PD sink IC, CC negotiation, etc.	Low (similar to wall-mount)
Connector	Barrel (e.g., 2.1 mm)	USB-C	Barrel (2.1–2.5 mm)
Availability at 12V/ 3A	Very common	Common, but PD sink design adds work	Common GST series bricks
Cost & BOM Impact	Low total cost	Higher total (charger + PD sink BOM)	Slightly higher than wall wart
User Familiarity	Very familiar	Also familiar, but expects USB devices	Common for laptops/routers
Mechanical Integration	Adapter hangs from outlet	Charger + cable; feeder still needs jack	Brick sits on floor or shelf

Feature	Facmogu 12V 3A Adapter	Mean Well GS36U12-P1J (36 W)	CUI SMI36-12-V-Px (36 W)
Output Voltage / Current	12 V / 3 A	12 V / 3 A	12 V / 3 A
Power Rating	36 W	36 W	36 W
Headroom for Motor Peaks	Minimal (just 3 A)	Minimal	Minimal
Barrel Connector Fit	Flexible (two barrel sizes)	Specified barrel size	Specified barrel size, known connector
Cost / Availability	Likely lower cost	Slightly higher cost but trade-off in reliability	Slightly higher cost but trade-off in reliability



Power Management – Barrel jacks

Feature	Standard open-frame PCB barrel jacks	Sealed or locking barrel jacks	Non-barrel alternatives
Pros	Cheap, widely available; easy to mate with 12 V adapters. Good EDA models and footprints; 2–3.5 A ratings common.	Locking mechanism prevents accidental disconnect. High current rating (~5 A); robust build; long life (5000+ cycles).	Simple, robust clamping of bare wires. No special plug format. Can handle high currents.
Cons	Can be unplugged accidentally. Not sealed. Current rating must be checked vs motor load.	More expensive. Special mating plug. Slightly more mechanical complexity and height.	Less user-friendly (requires screwdriver). Easier to mis-wire. No quick-connect feel.
Fit for Dog Feeder	Very good baseline choice	Great for mission-critical devices Arguably overkill for student dog feeder	OK for internal wiring. Not ideal for “user-facing” power input

Feature	CUI / Same Sky PJ-102A	Kycon KLDX-0202-AC	Switchcraft BKZ Series Locking Jack
ID / OD	2.0 mm / ~5.5 mm barrel family	2.0 mm ID / 5.5 mm OD	2.0 mm or 2.1 mm options, DC barrel family
Voltage / Current rating	~16 V DC @ 2.5 A	~24 V DC @ 3.5 A (variant dependent)	24 V @ 5 A
Mounting style	Right-angle, through-hole PCB	Right-angle, through-hole PCB with kinked pins	Right-angle PCB; through-hole, SMT, hybrid options
Special features	Simple open-frame jack	Some variants include switch contact	Locking bayonet mechanism, high-current design
Mechanical robustness	Good for standard duty	High (kinked pins, higher rating)	Very high; designed for critical equipment
Cost	Low	Medium	High

Power Management – Voltage Regulators

Feature	Linear Regulators	Non-Synchronous Buck Regulators	High-Current Simple Switcher Buck Regulators	Off-the-shelf Buck Modules
Typical Efficiency (12→5 V)	~42%.	~70–85 %.	~85–92 %.	Similar to IC used.
Current Capability	Up to a few A (with huge heatsink).	Up to ~3A.	Up to 5A.	Often 2–3A typical.
Thermal Behavior	Enormous heat: (12–5)·I, up to 35W at 5A.	Moderate heat, manageable at 2–3A.	Several watts of loss at 5A, heat sinkable.	Depends on module quality.
PCB Complexity	Very simple.	Moderate.	Moderate.	Very easy.

Feature	LM2596	LM2679	LM22678
Topology	Non-synchronous buck.	Non-synchronous buck.	Non-synchronous buck.
Vin range	4.5–40 V.	8–40 V.	4.5–42 V.
Vout option	Fixed 5V available.	Fixed 5V available.	Fixed 5V available.
Iout max	3A.	5A.	5A.
Typical efficiency (12→5 V)	~75–85% (design-dependent).	~85–92% (design-dependent).	~85–92% (design-dependent).
Layout difficulty	Low–moderate.	Moderate (comfortable for 2-layer).	Moderate–high (more EMI care).
Fit for 5V at 5A dog feeder	Undersized.	Excellent, recommended.	Excellent, but more layout-sensitive.

Software Comparisons

Mobile Application Stack - Frontend

- **Familiarity & Reduced Learning Curve:** Our team has prior experience with Flutter from previous coursework, allowing us to develop more efficiently and reduce implementation time.
- **Seamless Firebase Integration:** Flutter integrates directly with Firebase, enabling smooth real-time data handling, authentication, and backend communication.
- **Near-Native Performance:** Ahead-of-time compilation to native ARM code ensures high performance on iOS devices, providing a smooth user experience.
- **Consistent & Customizable UI:** Flutter's Skia rendering engine delivers consistent visuals across platforms while allowing full UI customization.
- **Rapid Development Tools:** Features like hot reload enable fast iteration, debugging, and UI refinement, accelerating overall development.

Category	React Native	Ionic	Flutter
Language	JavaScript / TypeScript (React)	HTML, CSS, JavaScript / TypeScript (Angular, React, or Vue)	Dart
Performance	High performance, close to native; slight overhead from JS bridge	Moderate performance due to WebView reliance; best for lightweight apps	Near-native performance via AOT-compiled Dart and direct rendering
UI Consistency	Matches native look using system components	Mimics native look using web components and CSS	Pixel-perfect, consistent UI across all platforms via custom widgets
Development Speed	Fast — shared codebase, hot reload, large ecosystem	Very fast — uses standard web technologies and tools	Fast — hot reload, unified widget tree, rich tooling
Learning Curve	Easy if familiar with React/JS	Easiest for web developers (HTML/CSS/JS skills reusable)	Moderate — requires learning Dart and widget-based UI paradigm
Ecosystem & Libraries	Mature, vast NPM ecosystem, backed by Meta	Large plugin base, strong web developer community	Growing rapidly, strong official support from Google
Integration with Backend (Firebase, REST APIs)	Excellent — native Firebase SDKs and REST API support	Good — uses JavaScript SDKs; works well with Firebase	Excellent — first-class Firebase integration and SDKs

Mobile Application Stack - Backend

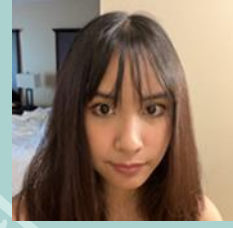
- **Fast & Beginner-Friendly Setup**: Firebase provides native Flutter SDK support and requires no server management, allowing us to deploy quickly without extensive backend experience.
- **Real-Time Cloud Synchronization**: Firestore and the Realtime Database enable instant data updates between devices, ensuring a responsive and seamless mobile app experience.
- **Built-In Authentication & Security**: Firebase offers secure, ready-to-use authentication methods (email/password, Google, anonymous, etc.), simplifying multi-user and multi-device management.
- **Automatic Scaling & High Reliability**: Powered by Google Cloud infrastructure, Firebase scales automatically with usage and maintains strong uptime without manual configuration.
- **Integrated Storage & Cost Efficiency**: Firebase Storage securely handles images and video snapshots, integrates with Cloud Functions and analytics, and offers a generous free tier with scalable pay-as-you-go pricing.

Category	Firebase	Supabase	AWS Lightsail
Ease of Setup	Easiest setup; no servers to manage; seamless with Flutter and mobile SDKs.	Simple setup with SQL-like structure; integrates quickly with Flutter via REST or SDKs.	Requires manual API and server setup; more configuration needed for databases and hosting.
Real-Time Communication	Built-in real-time sync with Firestore and Realtime DB.	Supports real-time updates using PostgreSQL's replication features.	Must implement custom WebSockets or MQTT for real-time data.
Authentication & Security	Built-in user auth (Google, email, custom tokens) and rule-based security.	JWT/OAuth auth with role-based access via SQL policies.	Uses AWS Cognito or custom JWT; full control over IAM and firewalls.
Database Model	NoSQL (Firestore) and JSON structure; ideal for live sync.	SQL (PostgreSQL) with relational querying and constraints.	Choose any (MySQL/PostgreSQL/MongoDB) — manual setup required.
Storage & Media Handling	Firebase Storage handles snapshots and logs easily.	Supabase Storage for files and media, similar to Firebase.	S3 integration for media; supports HLS streaming and large file handling.
Scalability	Auto-scales seamlessly with traffic; fully managed.	Scales with PostgreSQL cluster upgrades; moderate management.	Manual scaling by upgrading instances or adding load balancers.
Cost	Free tier + pay-as-you-go; cost increases with high read/write frequency.	Generous free tier; predictable pricing.	Fixed monthly per instance; predictable but may cost more idle time.
Maintenance	Minimal maintenance (serverless).	Low maintenance; open source with optional self-hosting.	Higher maintenance—updates, security patches, backups managed manually.

Embedded Software

- **Deterministic Real-Time Control:** C provides precise timing and predictable execution, ensuring immediate responses when the dog is detected sitting and the motor, LED, or speaker must activate.
- **Low Memory & High Efficiency:** With the ESP32-S3's limited RAM and processing power, C's low overhead and direct memory control make it ideal for efficient embedded execution.
- **Direct Hardware Access:** C allows direct interaction with registers, drivers, and peripherals, enabling accurate control of the motor, camera, LEDs, speaker, and Wi-Fi module.
- **Reduced System Overhead:** By using a structured main control loop with interrupt service routines instead of a full RTOS, the system avoids context-switching delays and unnecessary computational costs.
- **Industry-Standard for Embedded Systems:** C is the most widely used language for microcontrollers and real-time systems, providing reliability, performance, and long-term maintainability.

Category	C/C++ with FreeRTOS	MicroPython	TinyML Frameworks
Use Case	Low-level embedded control for MCU. Run components concurrently.	Python-based embedded control for MCU.	Compressed machine learning detection model for MCU
Advantages	Direct access to hardware registers and peripherals. Runs efficiently with minimal memory. High performance and timing precision. Real-time scheduling ensures deterministic behavior. Enables parallel task management.	Extensive built-in libraries for networking and sensors. Readable syntax.	Low latency. Offline operation. Enhances data privacy.
Disadvantages	Manual memory management. Limited abstraction. Longer development cycles. Requires careful task priority tuning. More complex.	Much slower execution. Limited real-time control. Higher memory requirement	Limited to small CNNs. Low accuracy.



Cloud Server

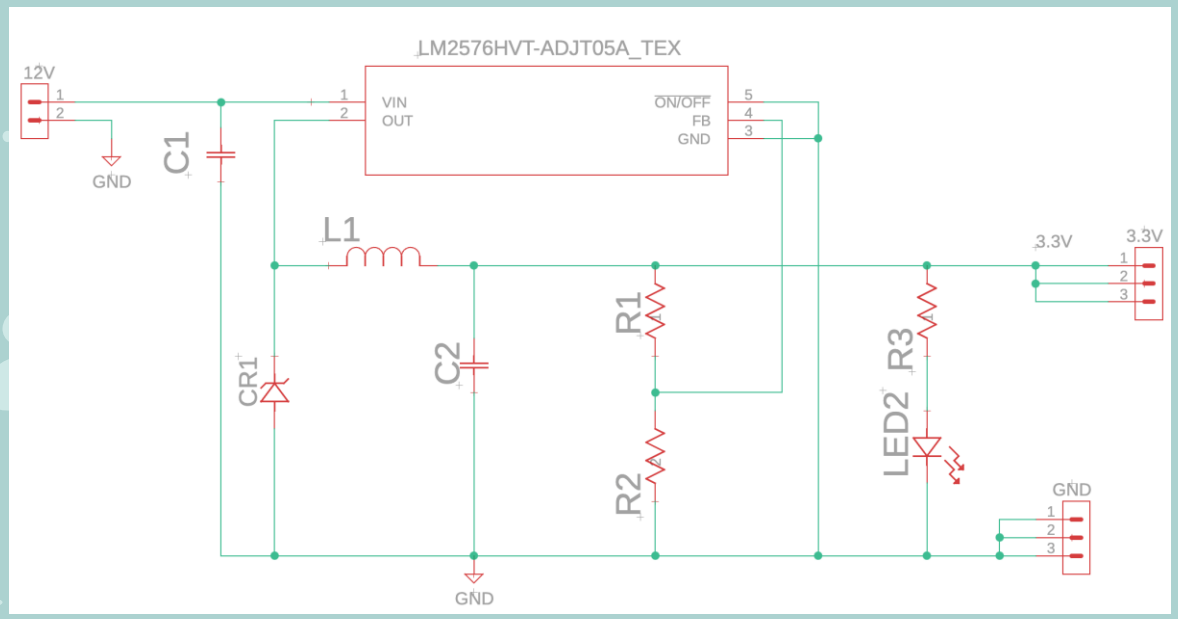
- **No sever management:** Google Cloud Run does not require any server management, so no Linux maintenance, firewall configuration, or patching.
- **Built for HTTPS interface APIs:** allowing for an easy integration with Firebase and request routing is handled automatically.
- **Auto-scaling:** It scales automatically for any future upgrades or multiple feeders.
- **Simple deployment:** build a Docker container, deploy, and get HTTPS URL.
- **Less operational overhead:** It does not need to run 24/7, unlike VMs and Amazon EC2.
- **Less complex:** Google Cloud Run is less complex compared to AWS SageMaker. AWS SageMaker is a full ML platform that is overkill for an inference endpoint, and it is expensive and more configuration.

Feature	Google Cloud Run	Google Compute Engine (VM)	Amazon EC2	AWS SageMaker
Setup	Easy	Medium	Medium	Hard
Server Management	None	OS	OS	Minimal
Auto-Scaling	Yes	Manual	Manual	Yes
Best For	REST APIs	Full Control	Full Control	Enterprise ML
CPU Control	1-8 vCPU (selectable)	Full Control	Full Control	Instance-based

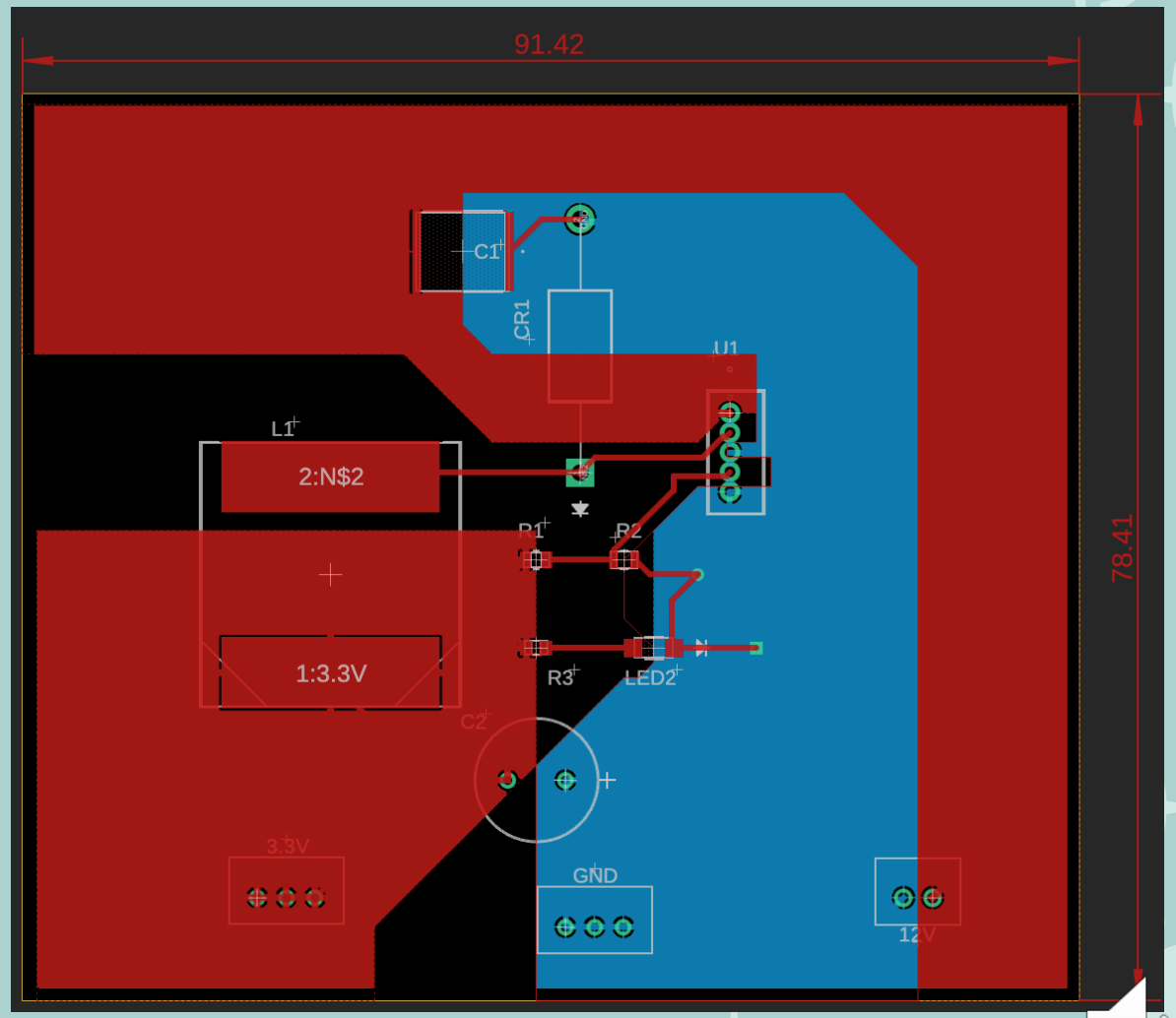
Hardware Design

PCB Design

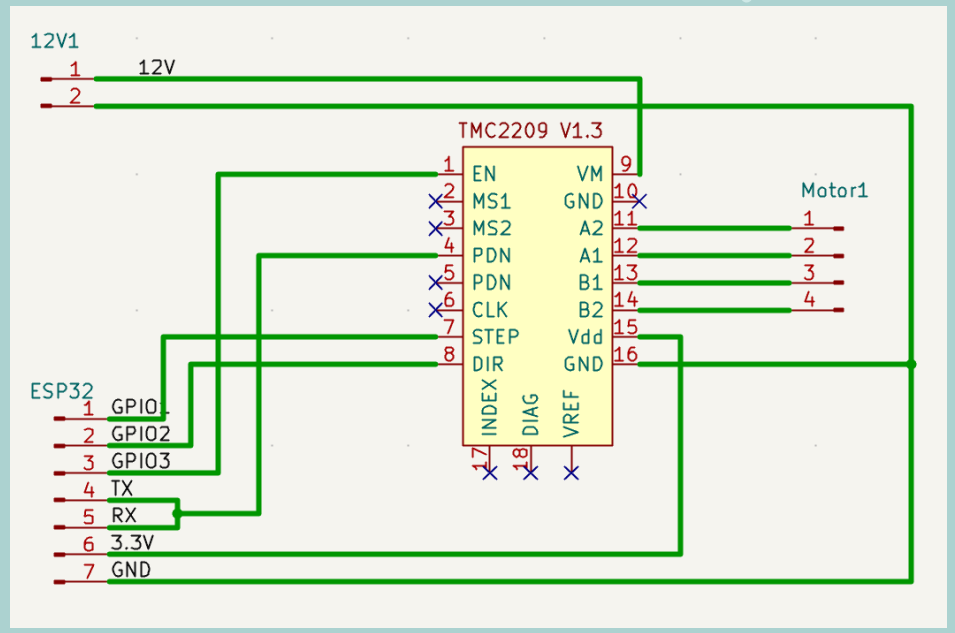
Voltage Regulators

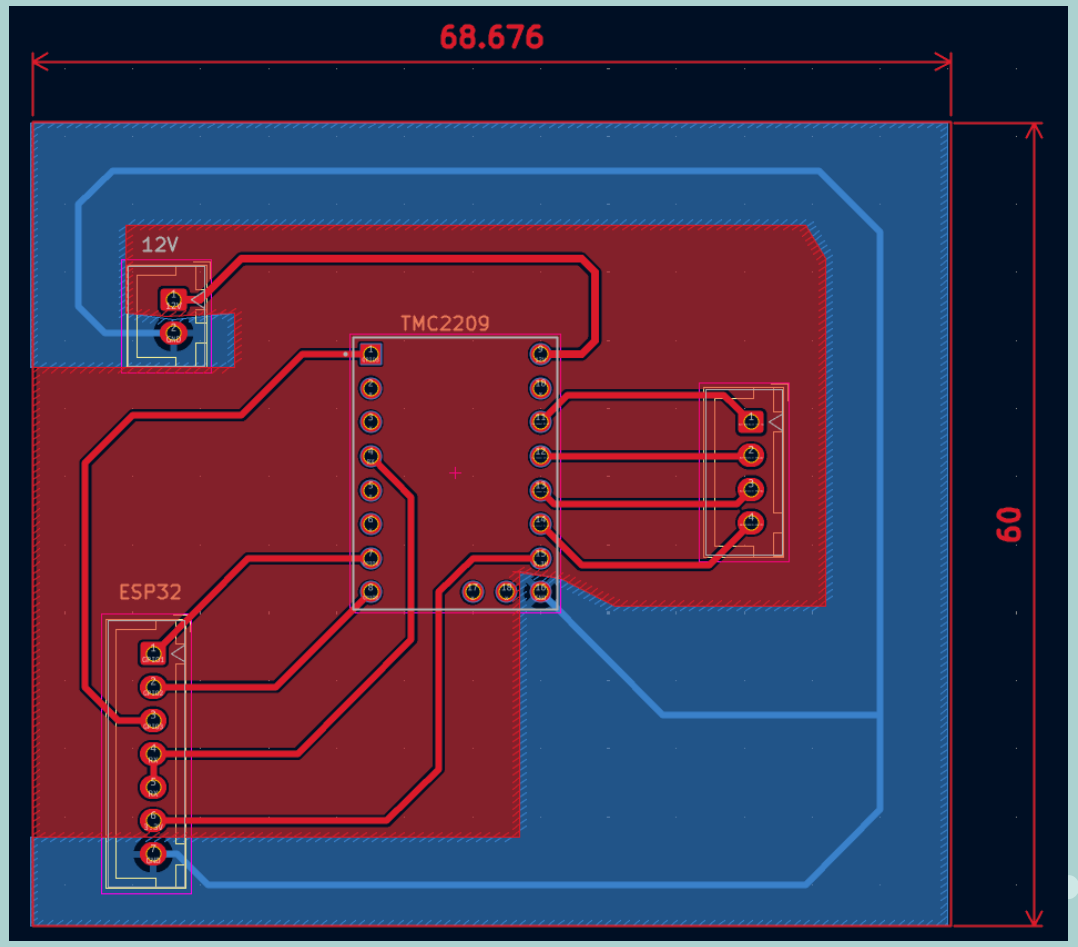


	R1	R2
3.3V	2.7k	1.6k
5V	11k	3.6k

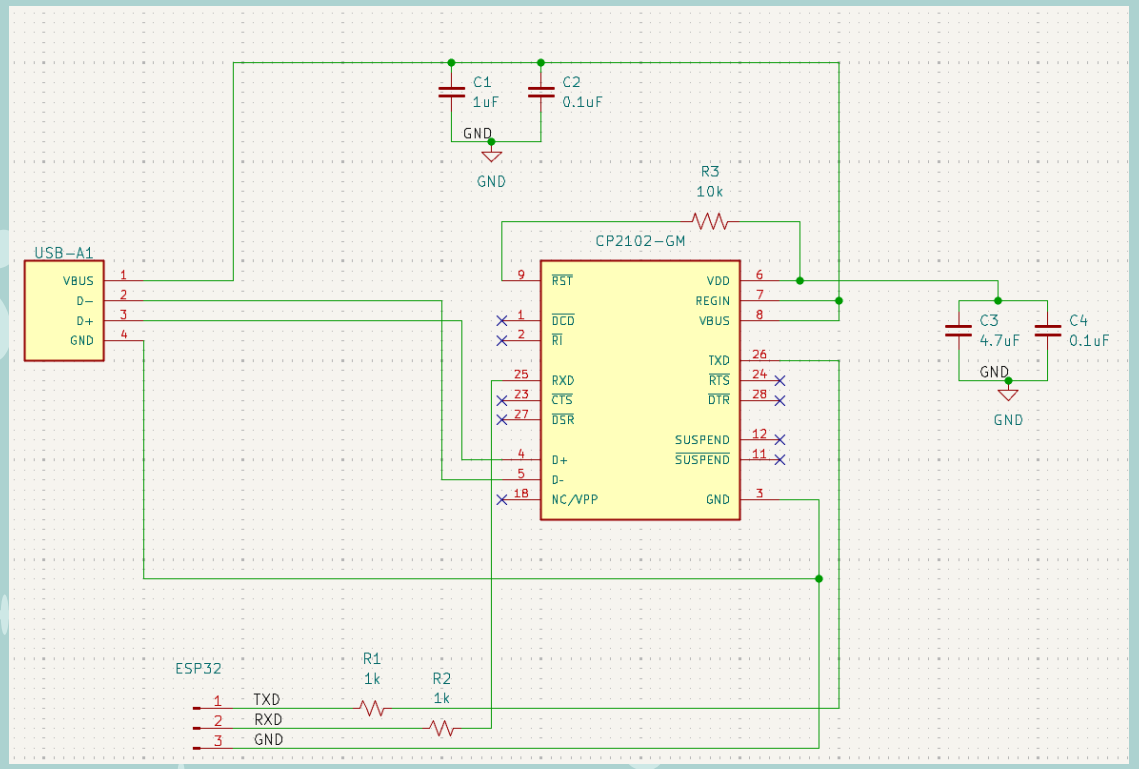


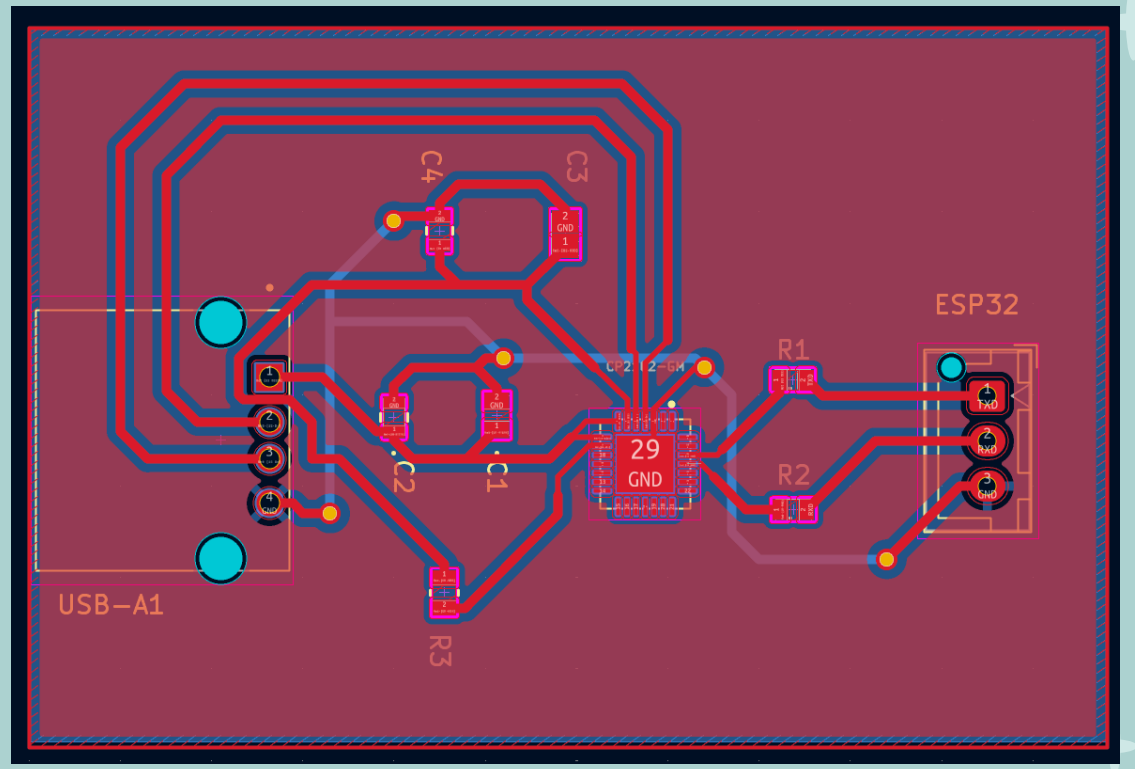
Motor & Motor Driver

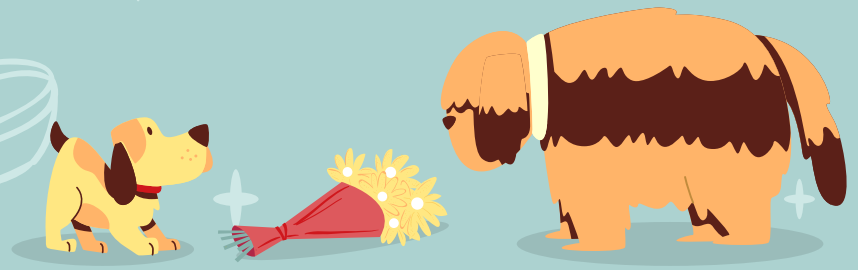




CP2102 programming



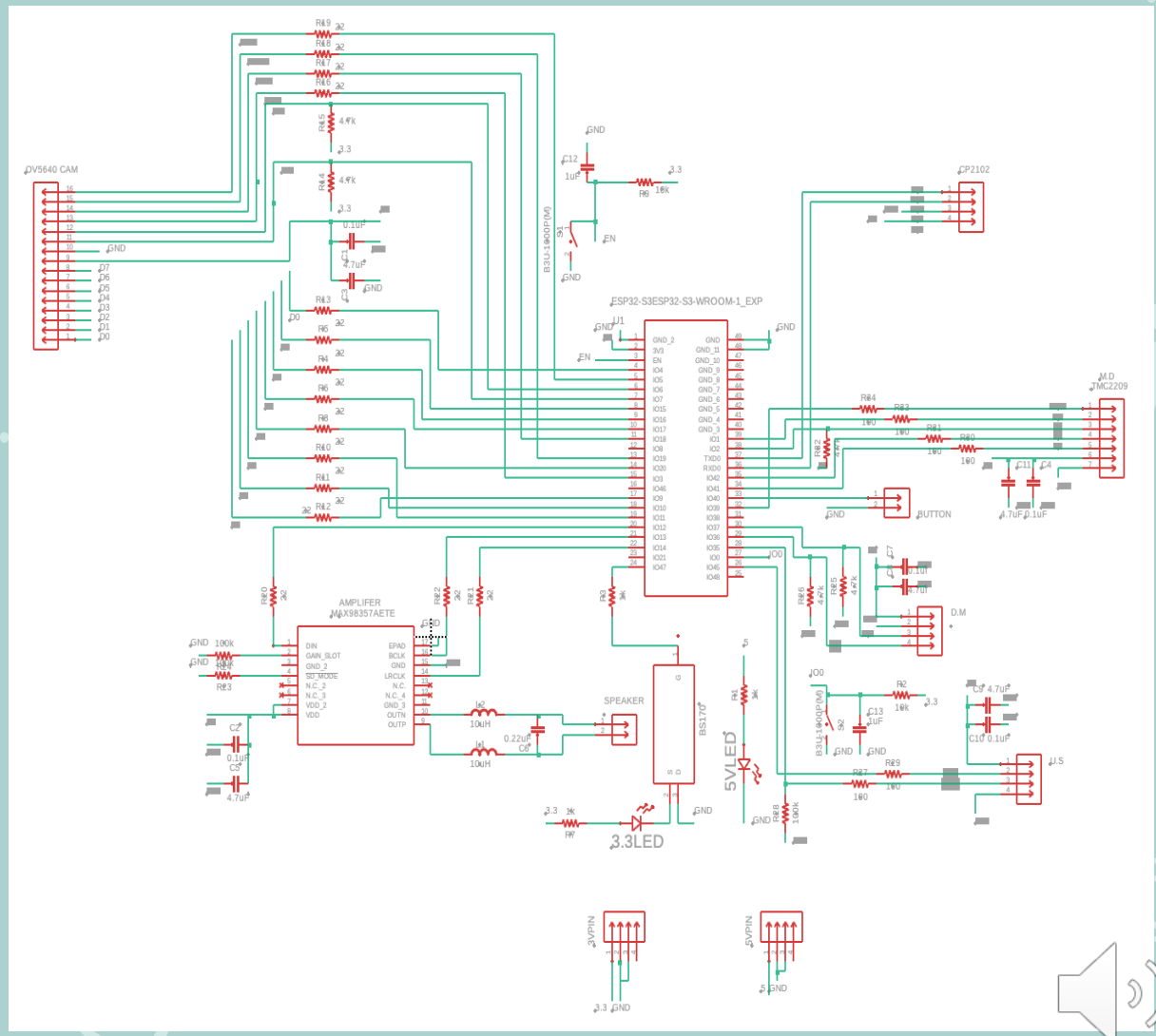




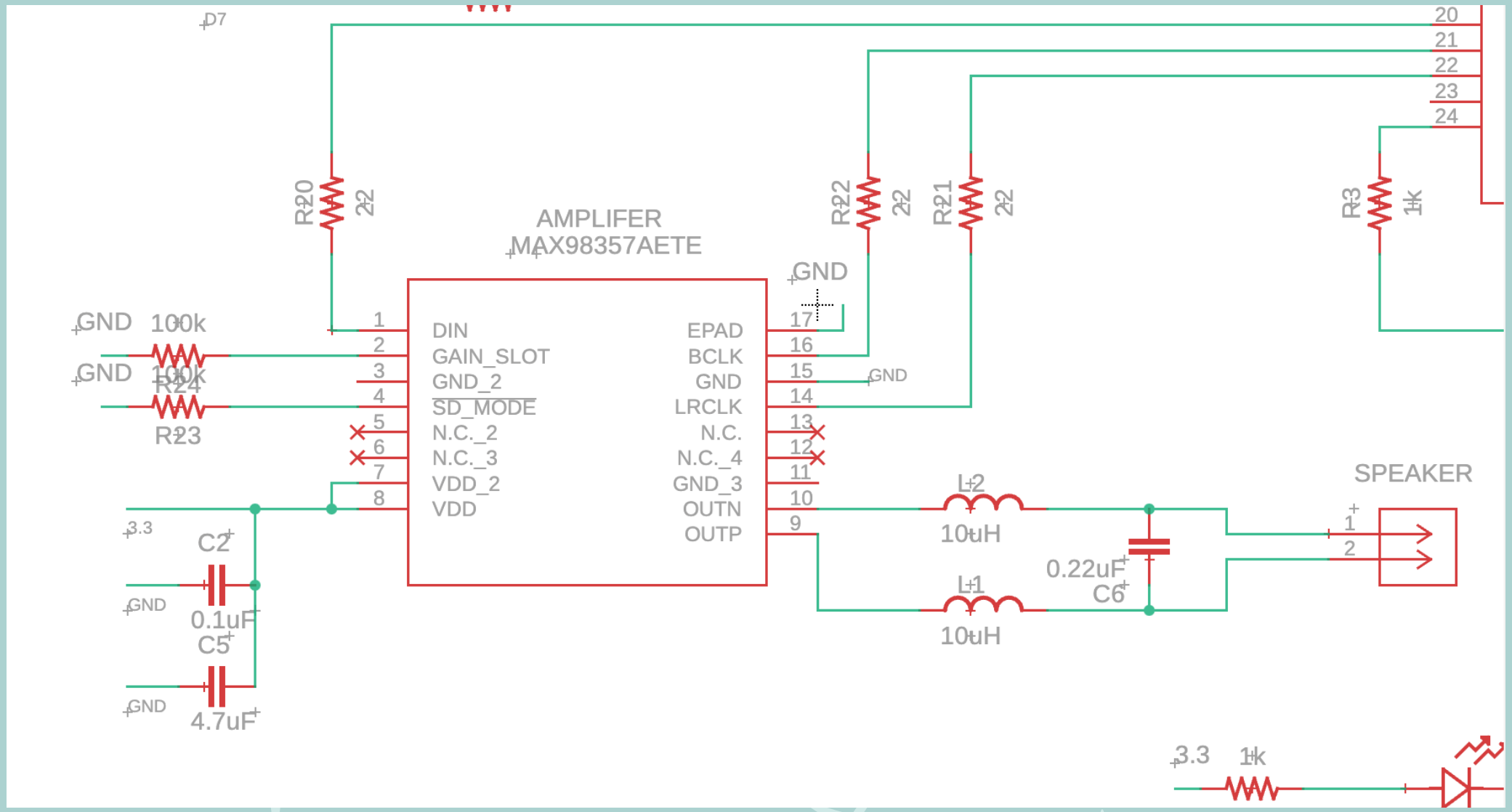
Main MCU

What The MCU PCB Contains

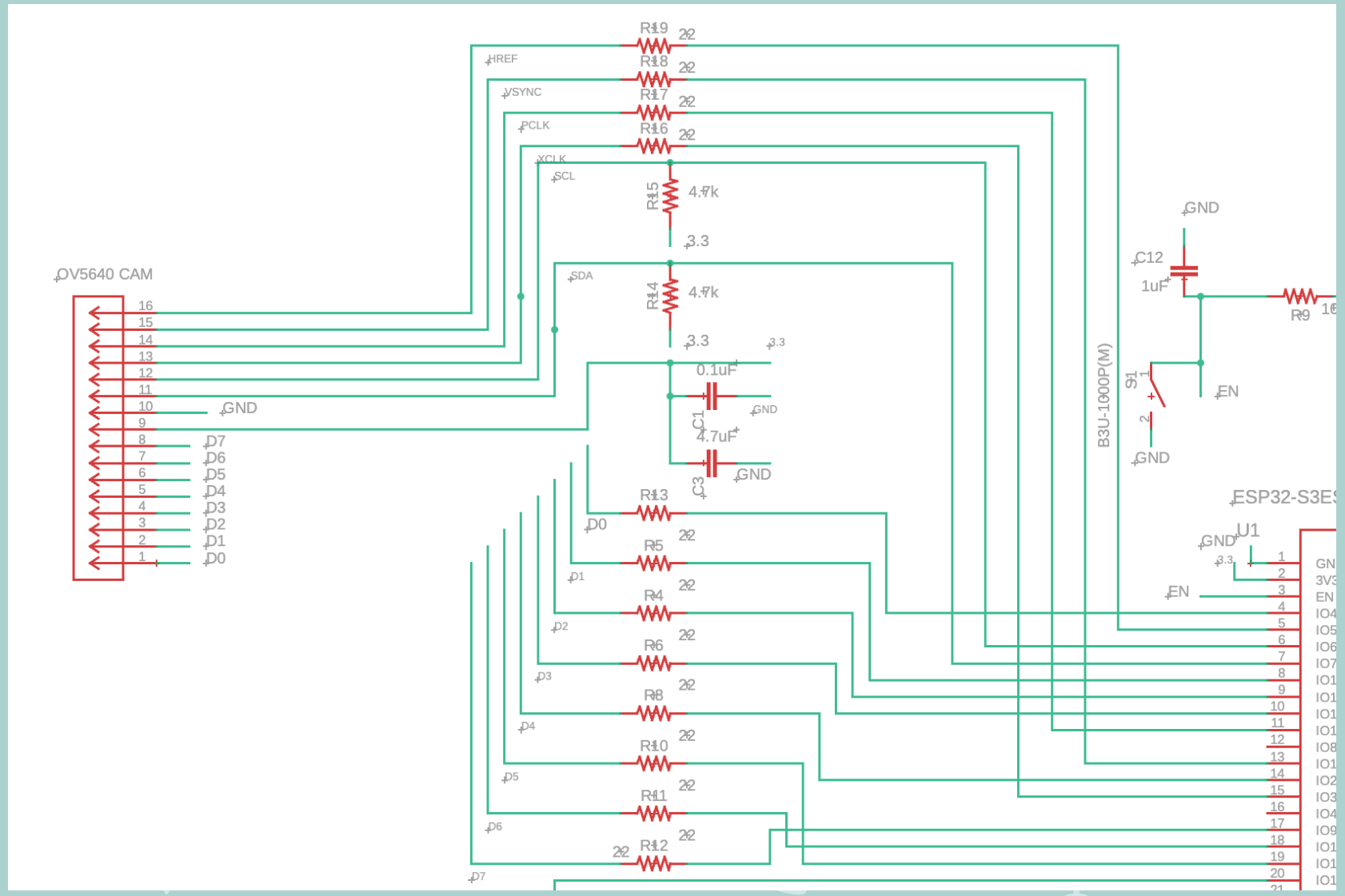
- ESP32-S3
- MAX98357A Amplifier
- Adafruit Speaker Connector
- Connecter to the CP2102 Programmer
- Connecter to TMF8701 Depth Module
- TMC2209 Motor Driver Connecter
- OV5640 Camera connecter
- Connecter to a pushbutton
- RCWL-1601 Ultrasonic sensor connecter



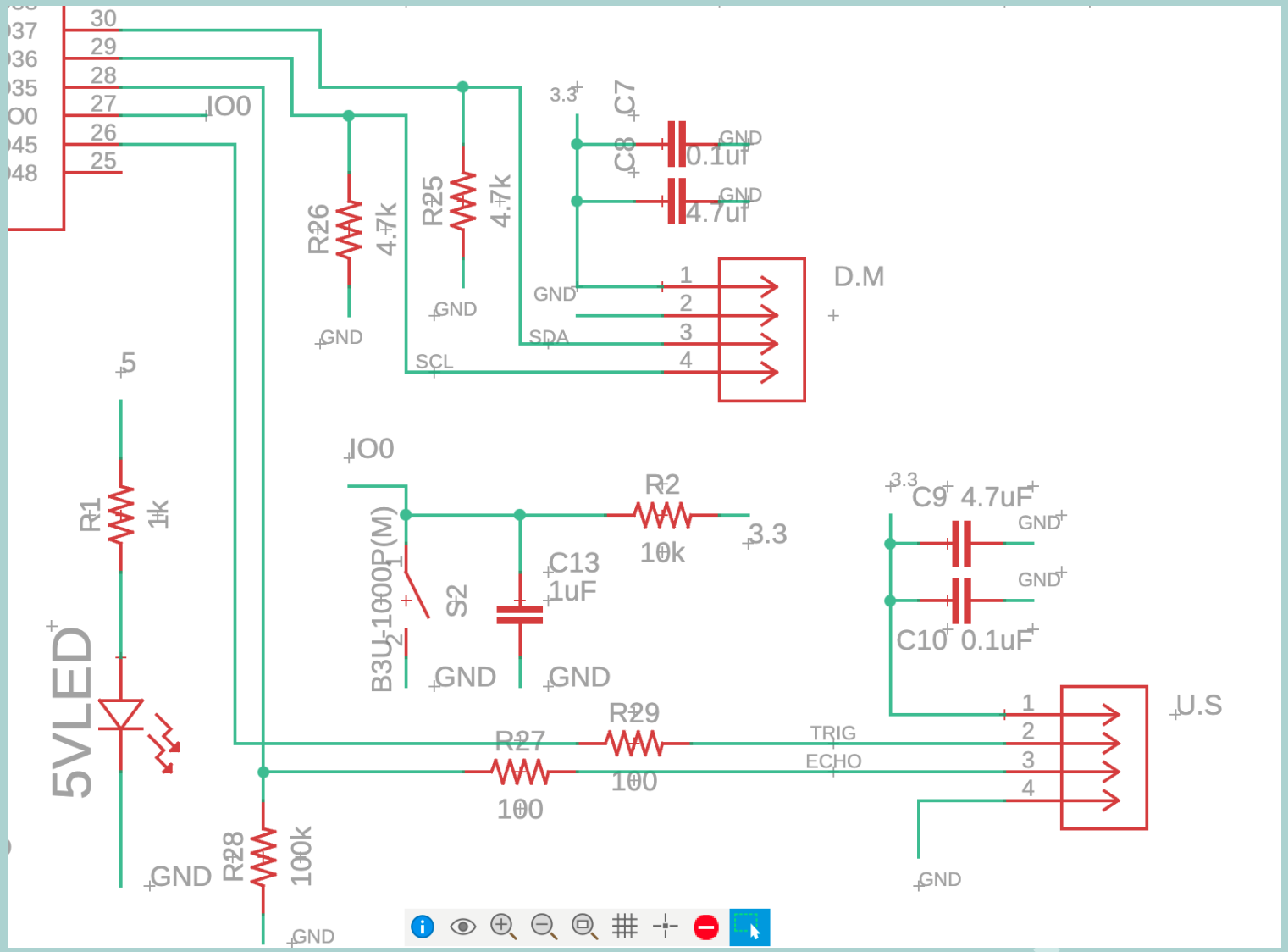
Main MCU: Amplifer



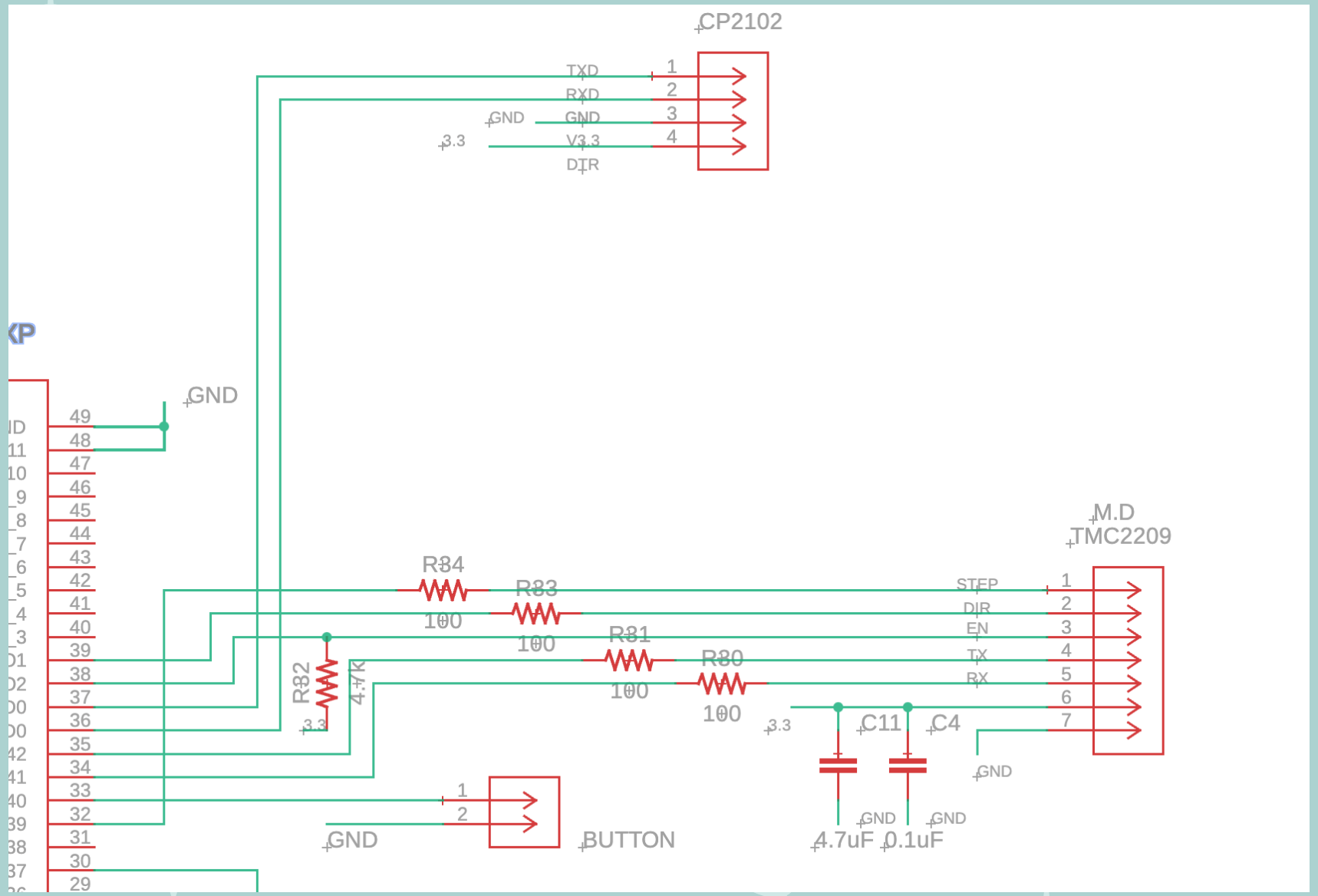
Main MCU: Camera



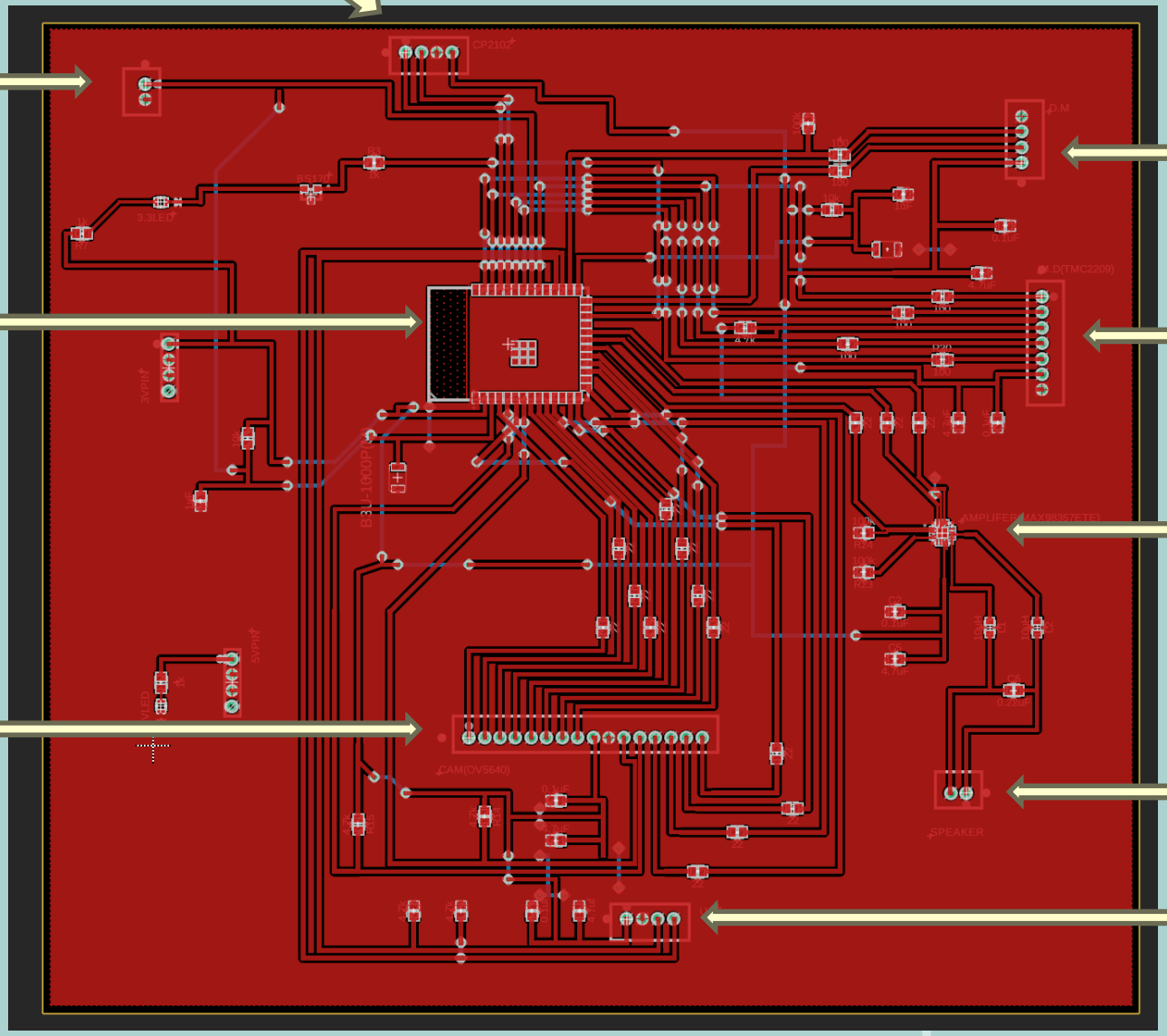
Main MCU: Depth Module + Ultrasonic sensor



Main MCU: CP2102, Motor Driver, and Pushbutton

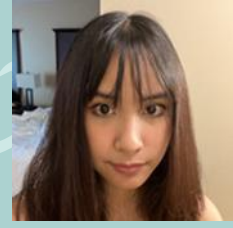


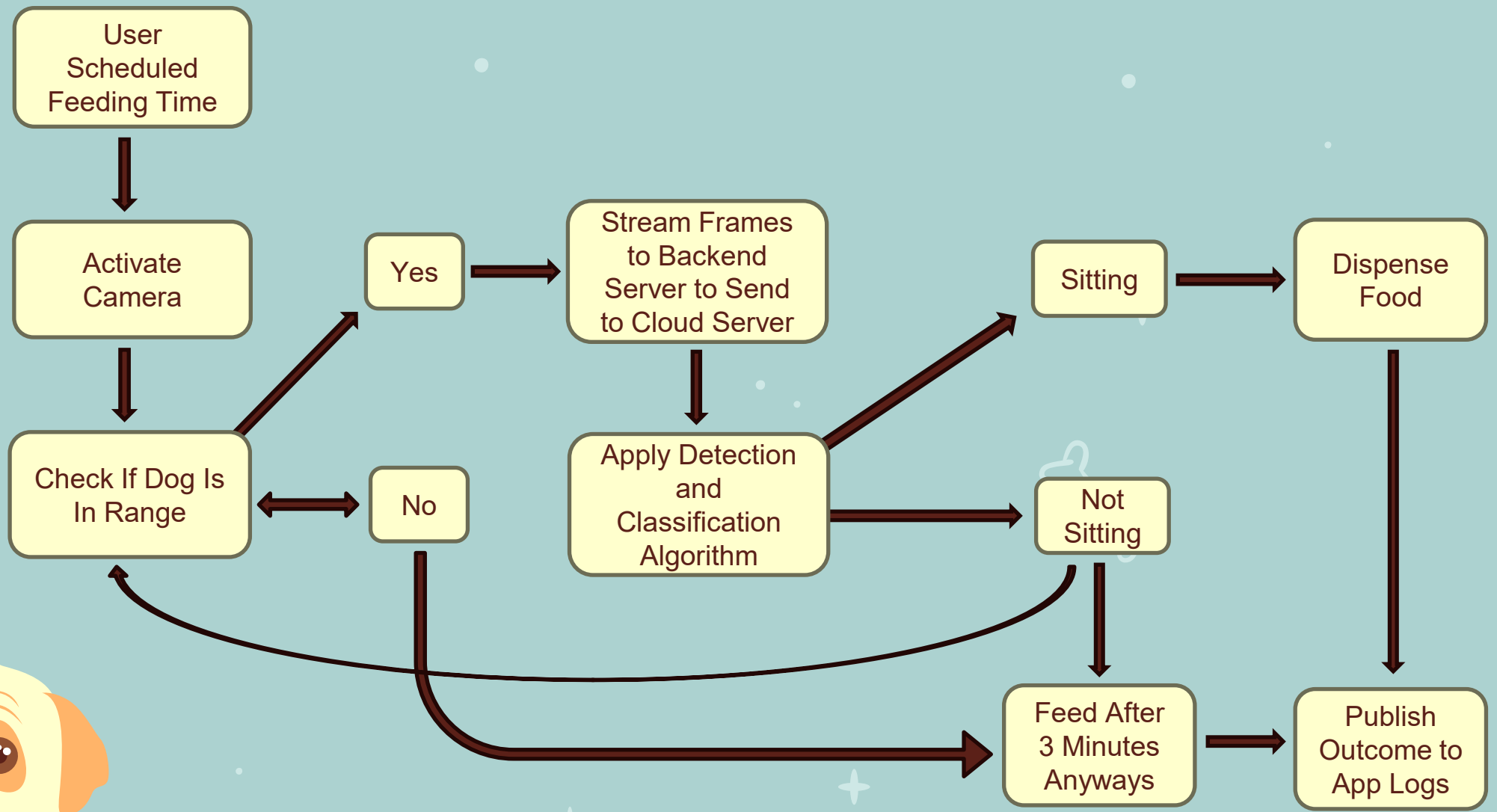
Main MCU Layout



Software Design

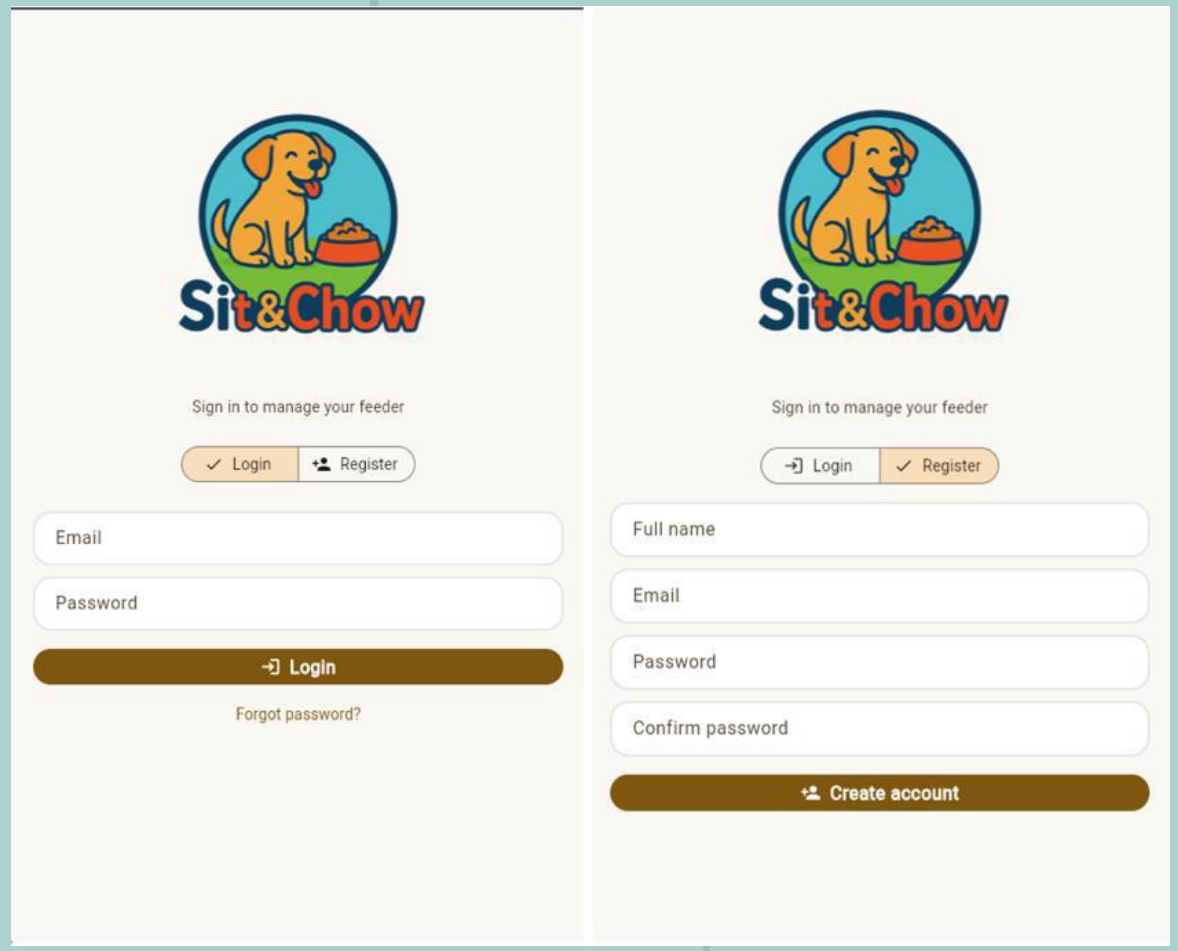
Software Design
Scheduled Feed Workflow





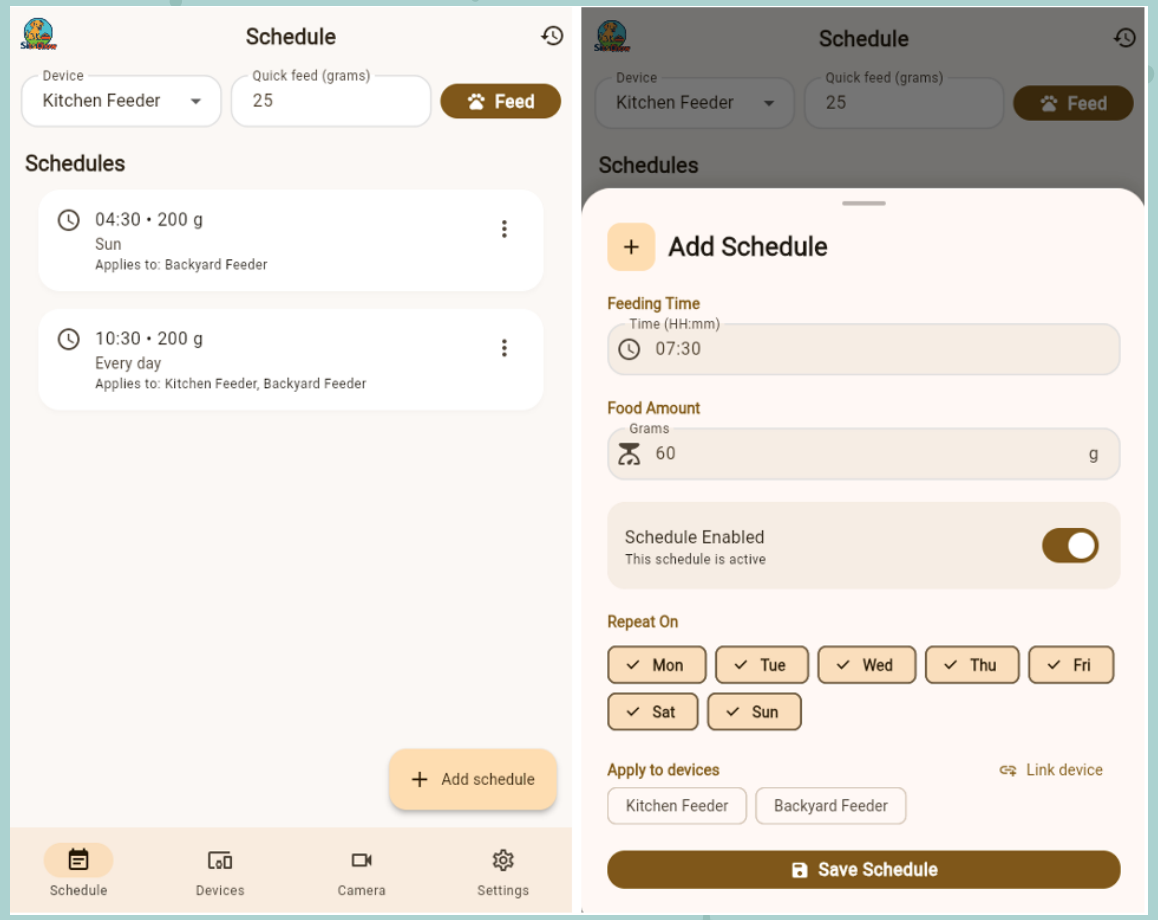
Mobile Application

Mobile Application – Login and Register



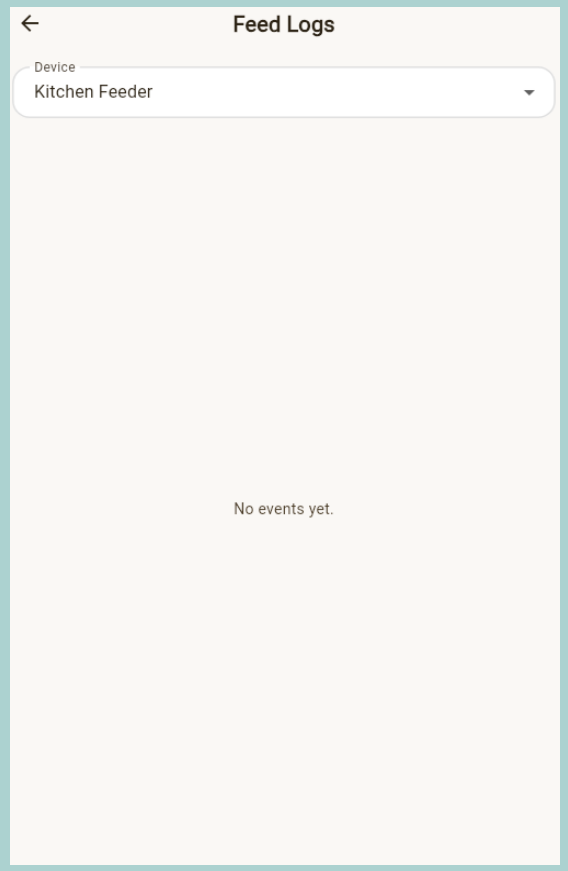
- The first page that the user sees is the login and register page
- When they register, the information they enter is sent to the Realtime Database in Firebase to authenticate the user in the login process
- Once they register or login, they are sent to the landing page

Mobile Application – Schedules

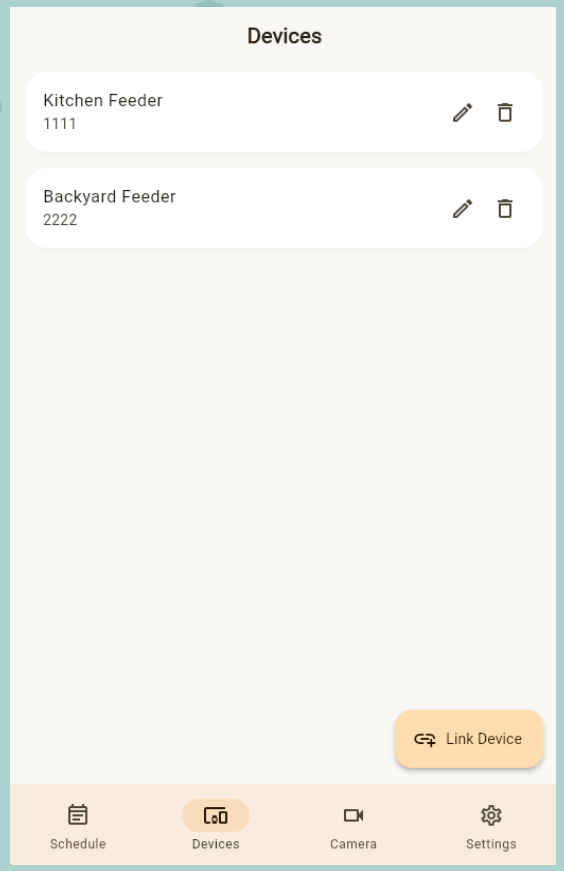


- The schedules page displays all of the schedules the user has created
- A quick feed option is available to immediately activate the feeder, bypassing the detection model should the user need to do so
- The user can create a new schedule, assigning different days, times, food amount, and devices the schedule is assigned to
- The user can freely edit or delete the schedules created at any time

Mobile Application – Feed Logs & Devices

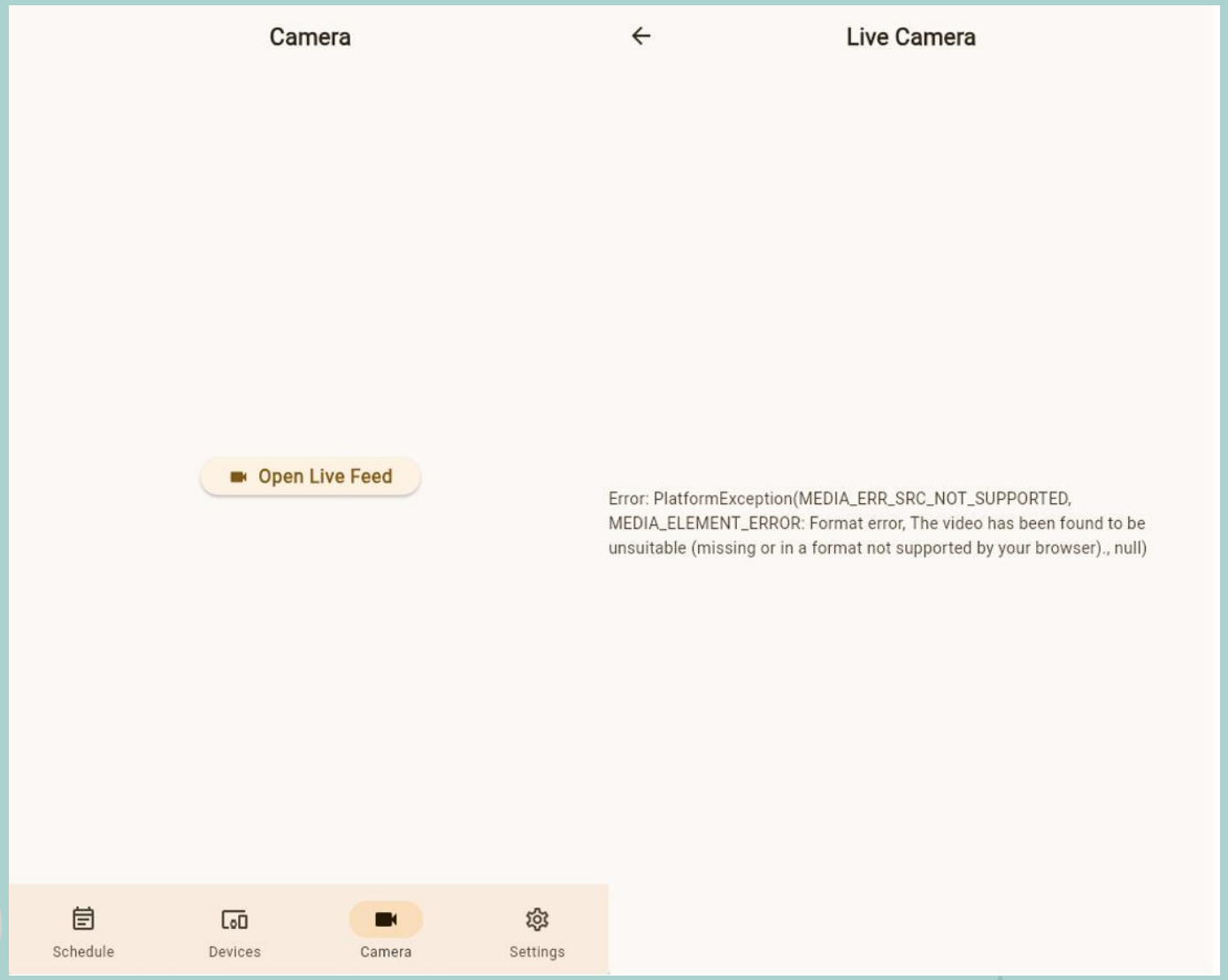


- By clicking the history icon on the top right of the schedules page, the feed logs page appears
- All this marks is whether or not a sitting position was detected within the feeding time frame
- If no sitting position is detected within 5 minutes, a failure will be marked, otherwise it will be marked as a success



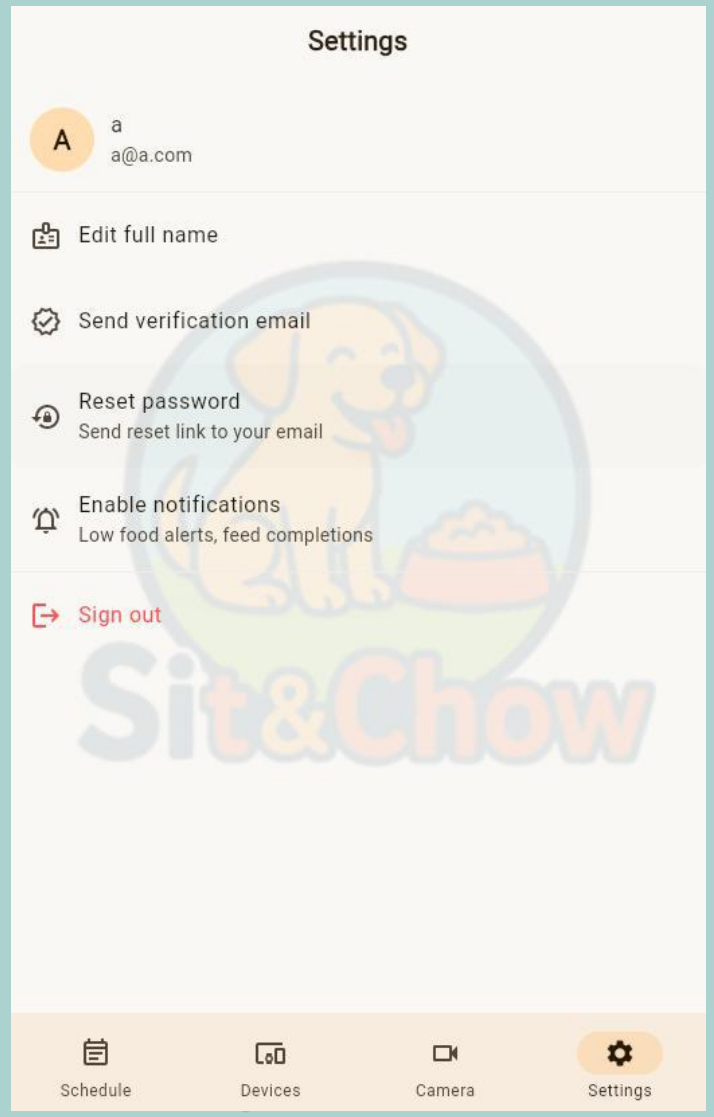
- The device page displays all of the currently linked devices
- The user will have to manually input the Device ID to connect to it
- The Device ID is randomly generated and will be given to the user per device
- The user can name the device once connected and can then freely edit or delete said device

Mobile App – Live Camera Feed

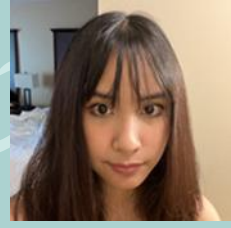


- The camera page will not immediately go to the live camera feed and will instead have an interactable button in the center to enter the live camera feed
- We do this to reduce performance costs because the user may accidentally open the camera page and doing this without the extra page will start the live feed events, possibly causing significant performance issues
- Once the live feed page is open, the live feed events will activate, and the user will be able to see through the camera
- There will be an interactable microphone symbol that allows the user to speak through their phone out through the speaker on the dog feeder

Mobile Application – Settings



- On the settings page, the user will be able to change their full name
- They will be able to verify their email address
- A reset password function is available should the user wish to change their password
- They are also able to enable their notifications on this page if they turned it off before
- Lastly, they can sign out of their account if they wish to do so, sending them back to the login and register page



Posture Detection and Classification Algorithm

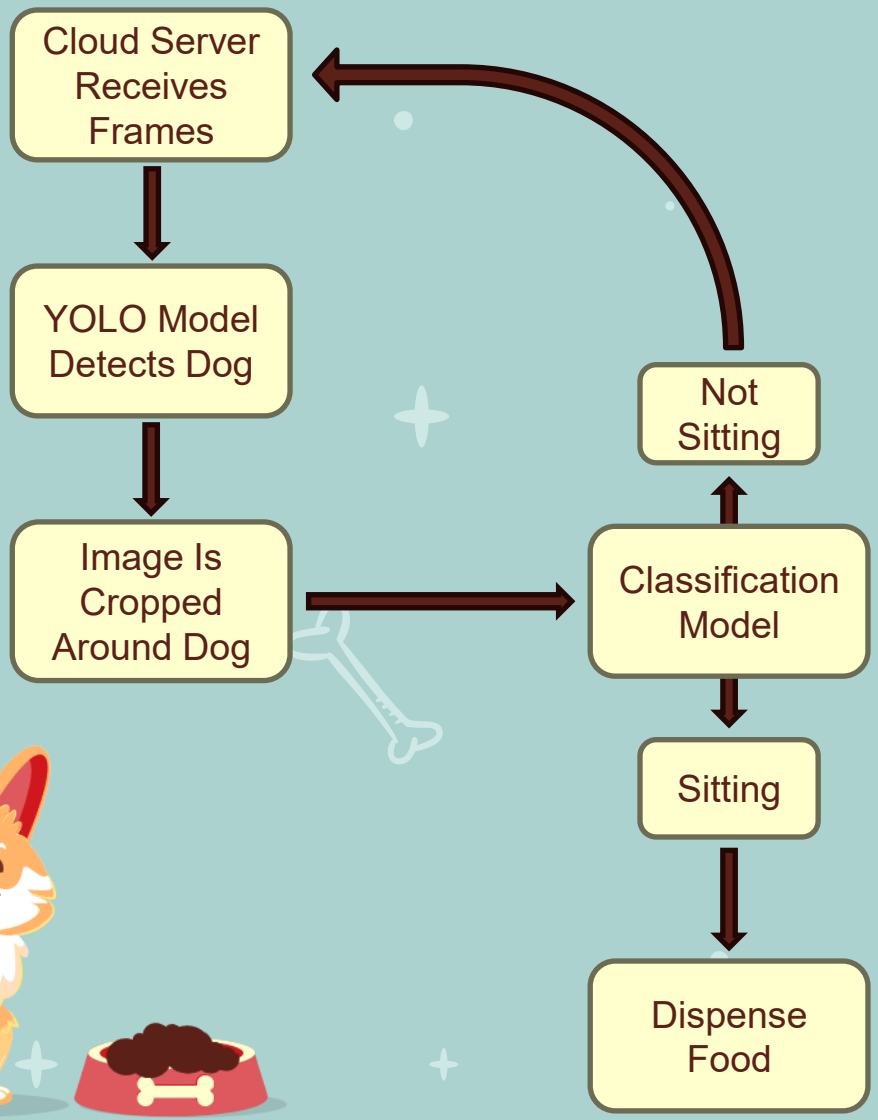
The detection and classification pipeline operates in 5 main stages:

- Getting the image
- Detecting the dog
- Displaying and cropping the bounding box
- Classifying the posture
- Executing the event

YOLO is a computer vision model that is pretrained on the COCO dataset. Dogs are one of the objects it has learned to detect.

- A box will be drawn around the dog, and the image will be cropped around the box.

The new image will be passed through a classification model to determine if the dog is “sitting” or “not sitting.”



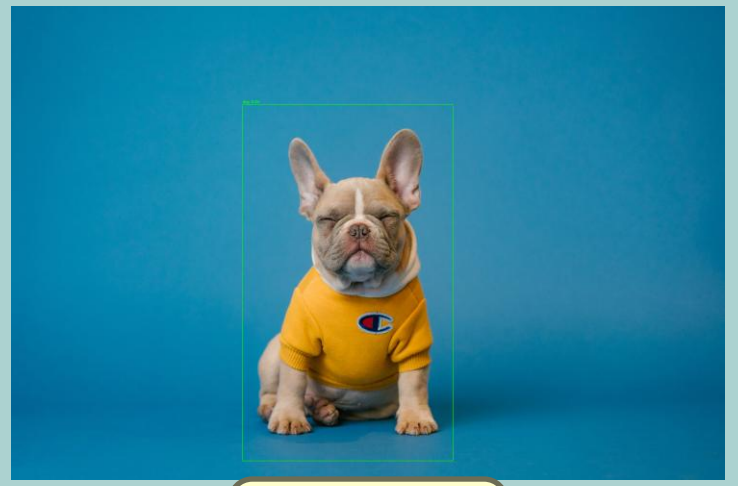
How it works:

- The mobile app server will send the images to the Google Cloud Run server. A container is created to load the models and run the inference. The output will be sent back to the system until the food is dispensed.

Which YOLO model?

- We need to measure the detection rate, confidence, bounding box, and inference time.
- Models: YOLOv11, YOLOv8, and YOLOv5
- The nano version will be tested, and the best model will be tested amongst its other versions to give the average precision.
- Then the best model will be tested on a set of images that will be like the ones seen from the system's camera.
- Further testing will be done on the cloud server to check inference time.

	model	overall_mAP50-95	overall_mAP50	dog_AP50-95
1	yolo11s.pt	0.468125	0.634499	0.714193
0	yolo11n.pt	0.392397	0.548619	0.649005
2	yolov8n.pt	0.371439	0.521146	0.592740
3	yolov5n.pt	0.340847	0.491984	0.520990

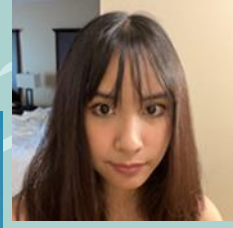


YOLO Model Detects Dog

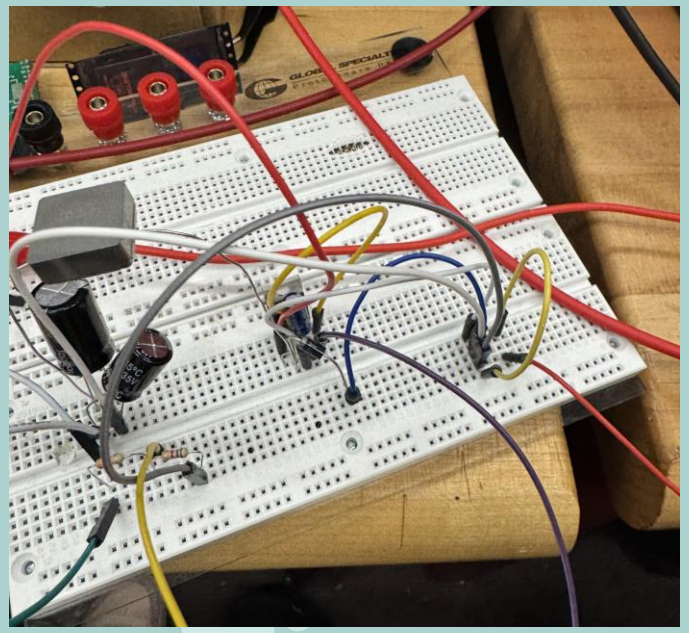
Image Is Cropped Around Dog

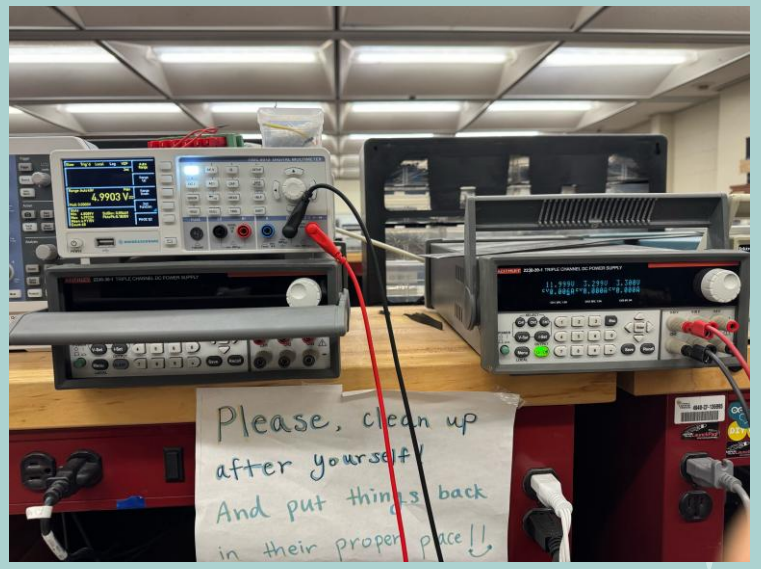
Cloud Server Receives Image

Classification Model

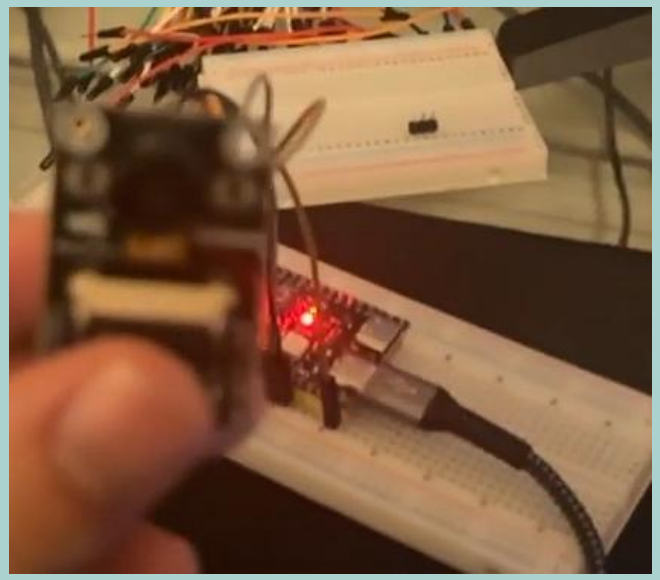


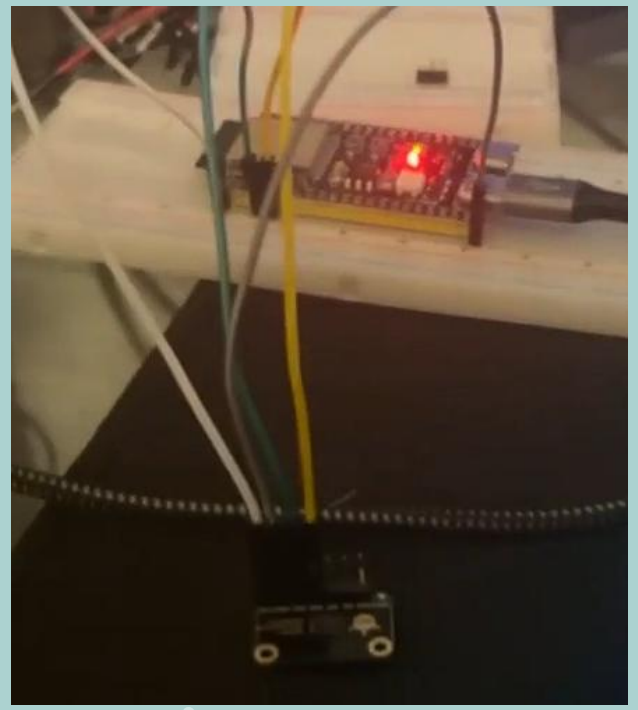
Prototyping and Testing

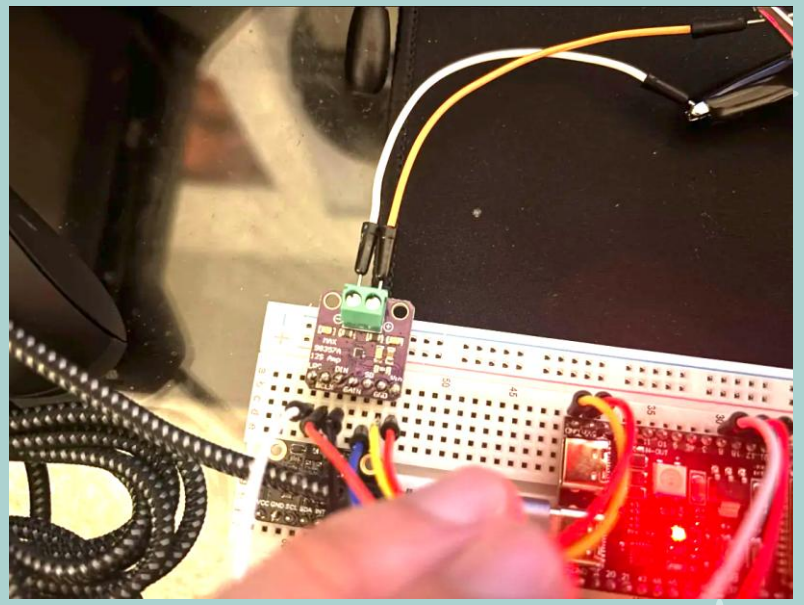


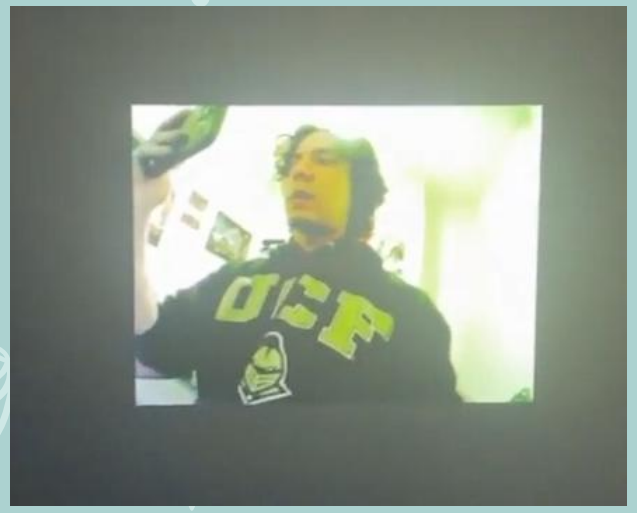


Prototyping and Testing



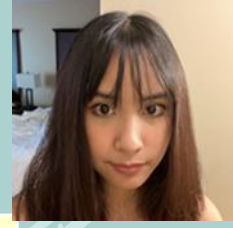






Administrative Content

Contributions

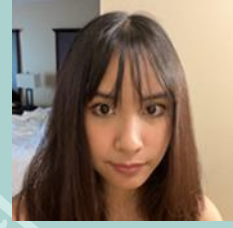


Senior Design 1	
Andres	Project Description, MCU Selection, Mobile Communications, MCU and Mobile Application Software Design, Case Study, Software Testing
Andrew	Hardware Selection (Camera), Standard Constraints, Hardware Design, PCB
Maria	Introduction, Project Description, Hardware (Depth Module), Detection and Classification Model, Software Constraints, Software Testing, BOM
Natalie	Hardware Selection (Motor, Motor Driver, Speaker, Amplifier, LEDs, Button, Sensing Storage Capacity, Power Management), Case Study, Hardware Design, PCBs, Hardware Testing, BOM, Milestone
All	HOQ, Specification Table

Senior Design 2	
Hardware	
Andrew	ESP32, Camera, 2 Sensors, Amplifier-Speaker, Button
Natalie	Motor driver - Motor, Voltage Regulators (3.3V & 5V), CP2102
Software	
Andres	Embedded Software, Mobile Application
Maria	Detection and Classification Pipeline, Cloud Server
All	Testing together to see if the product works

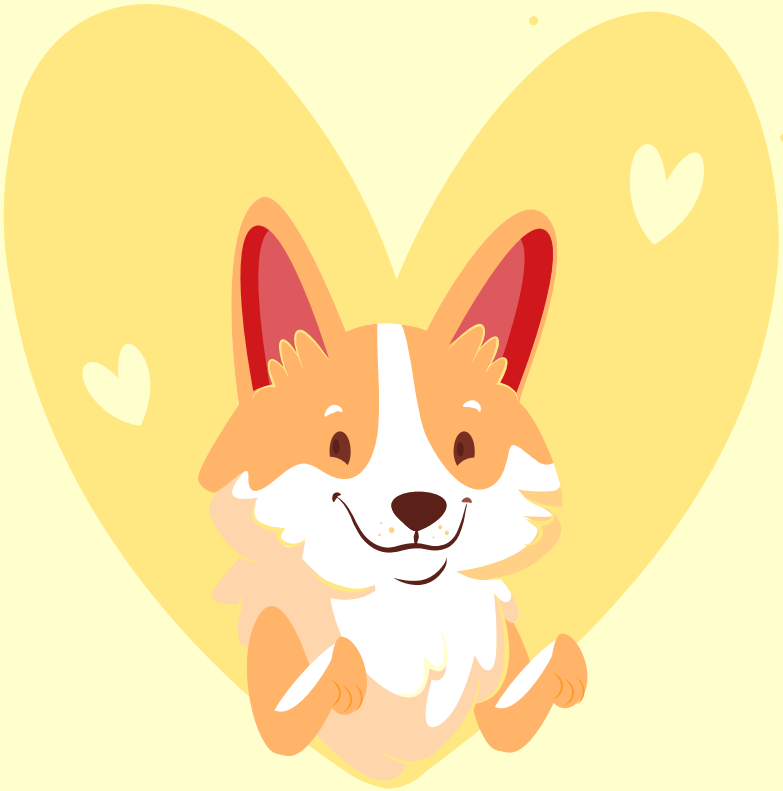
Budgeting

Component	Quantity	Price Total
Stepper Motor	1	3.33
Motor	1	4.59
Power Adapter	1	9.99
Barrel jack	1	0.65
Camera	1	13.76
Voltage Regulators	2	18.64
Amplifier	1	5.95
Speaker	1	1.95
Button	1	4.39
CP2102	1	8.88
Ultrasonic Sensor	1	3.95
Depth Module	1	13.00
ESP32	1	10.67
PCBs	5	99.10
Mechanical assets		TBD
Total Cost		**198.85**



Progress and Plan for Completion

Goal	Finish By Date
Individual Hardware Testing (Completed)	1/16
Individual Embedded Software Testing	1/16
Finish Detection and Classification Pipeline	3/6
1st PCB Iteration Complete	3/6
Design and 3D-Print Encloser	3/6
Test and Troubleshoot System	4/10



THANKS