AURA

Autonomous Undercar Risk Avoidance

Group 2

Critical Design Review Presentation

Motivation & Background

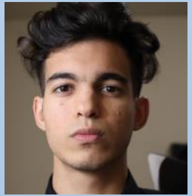
- **Sensing Gap in the Underbody of Autonomous Vehicles (AV)**
    - Autonomous sensing systems covers 360˚ around the car ABOVE ground
    - NO dedicated sensing system beneath vehicle body
    - Wide and shallow blind region of 6.5” clearance
    - Animals and low-profile objects are undetectable

AURA proposes an AV underbody sensing and animal deterrent system

SENSING DETECTING DETERRENT

Our Team

Theresa Dinh
Optics and Photonics



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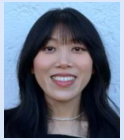

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Goals & Objectives

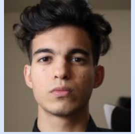
Goals

- Basic
  - Capture footage for verification/processing
  - Detect animals beneath demo vehicle upon startup
  - Prevent motion while animals are present and deter them
- Advanced
  - Species Identification
  - Real-time response
- Stretch
  - Scalable to full-sized AV

Objectives

- ➢ Dual NIR front/rear sensing modules + LCD display
- ➢ YOLO-based detection
- ➢ Audio/visual deterrent + motor interlock
- ➢ Raspberry Pi-based classification
- ➢ Embedded processing + relay control
- ➢ Modular optical and sensing architecture

Demonstrable System Specifications



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Electrical Engineer

Specification	Description	Target Value and Unit(s)
Startup Safety Latency	The time from animal detection to the "prevent movement" interlock activation.	< 2 seconds (Demonstrable)
Detection Success Rate	The accuracy of the AI in correctly identifying an animal versus benign debris.	> 95%
Minimum Detection Height	Minimum vertical height of target living animals detected by AI.	> 3.0 inches
System Engagement Threshold	The speed above which the camera retracts, and the interlock is safely disabled to prevent mid-drive stops.	1 mph (Demonstrable)
Total Deployment Time	Time required for cameras to fully extend from the safety housing upon ignition.	< 6 seconds (Demonstrable)
Ultrasonic Repellant Frequency	Frequency range of high-frequency alarm.	30 kHz – 45 kHz
Operational Temperature	The environmental range in which electronics and motors must function.	-10°C to +50°C
Hazard Clearance Verification Time	Time for the system to confirm clear status after deterrent use.	5 seconds
Total estimated cost	Total estimated cost for all integrated hardware components.	< $750 Estimated
Battery	Total peak power draws as a percentage of the ride-on car's battery capacity.	~50 W

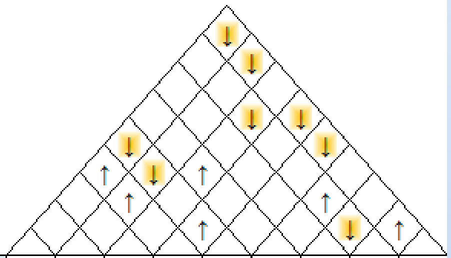
House of Quality

- The House of Quality translates customer needs into measurable engineering targets, showing which design parameters most strongly drive cost, reliability, and performance tradeoffs.

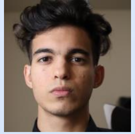
Correlations	
Positive	↑
Negative	↓
None	

Relationships	
Strong	↑↑
Positive	↑
Negative	↓

Direction of	
Maximize	+
Target	
Minimize	-



Direction of Improvement	Customer Requirements (Explicit and Implicit) / Engineering Requirements	Horizontal FOV	Vertical FOV	Startup time	Detection Accuracy	Camera Range	Wireless Latency	Alarm Response Time	Power Consumption	Cost
	Direction of Improvement	+	+	-	+	+	-	-	-	-
-	Cost	↓	↓	↓	↓	↓			↑	↑↑
+	Power Efficiency				↓		↓		↓	
+	Reliability				↑↑		↑	↑↑		
+	Ease of Installation			↑					↓	↓
-	Size	↓	↓	↓		↓				↑
	Target	96.6°	12.3°	<20s	95%	> 5ft.	<100 ms	<500 ms	~ 50 W	Estimated 1,516.54$



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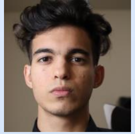
System Visualization



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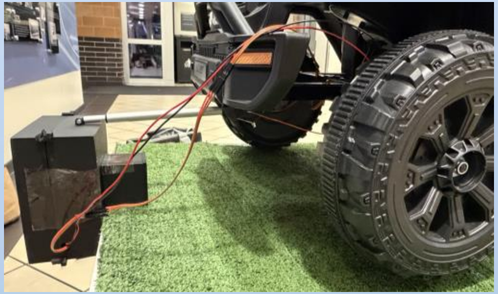
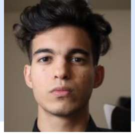
Camera fully deployed



Camera fully retracted

- **Summarized Functionality**
  - Cameras on both ends, pointing under the car, are attached to tip of actuators
  - Actuators extend on startup and retracts once clear
  - AI detection triggers the rest of the system
    - Deterrents, Notifications, Motor interlock

Block Diagram



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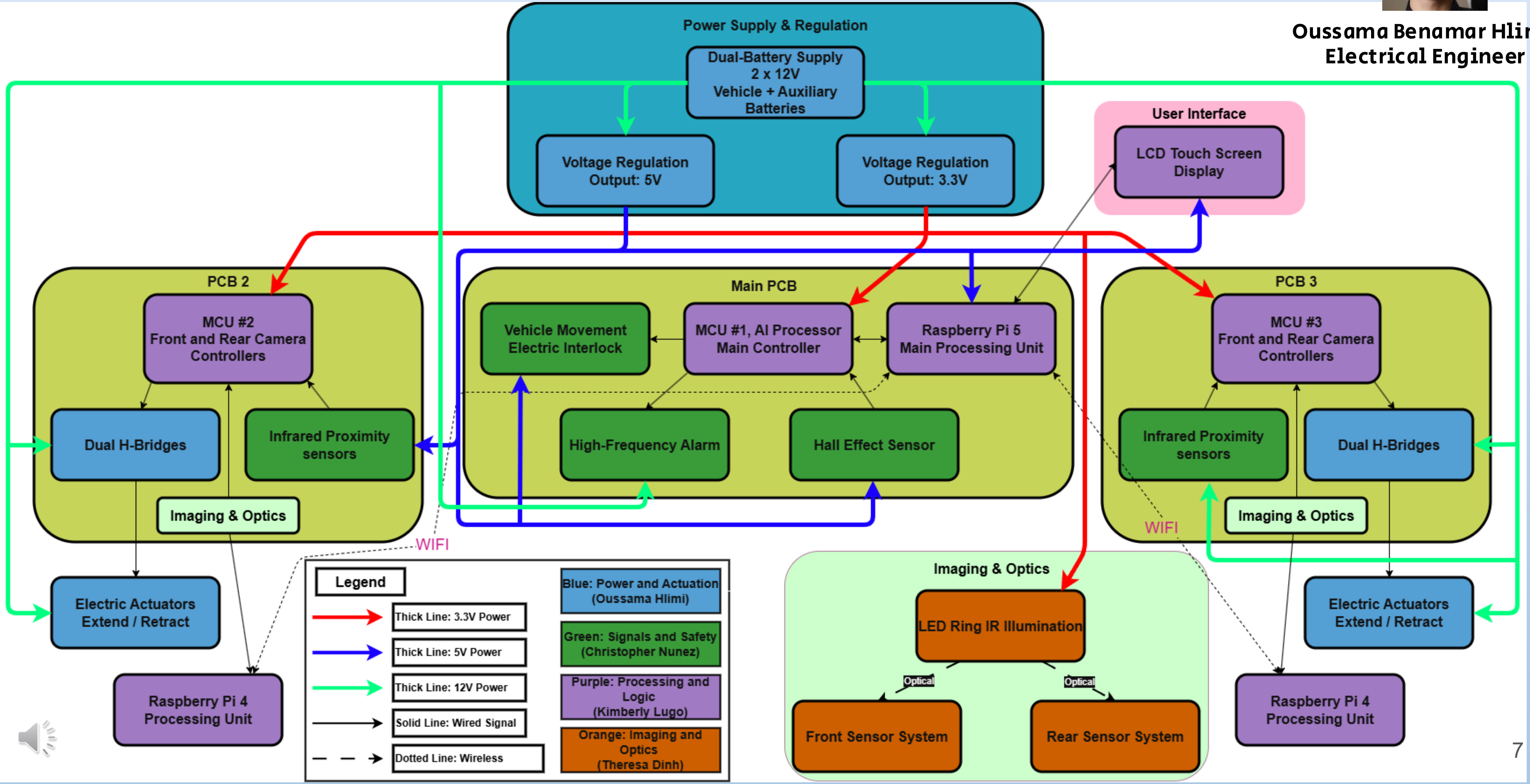

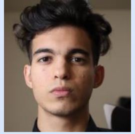

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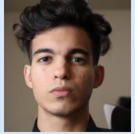
Hardware Selection

Proximity Sensor: Technology Comparison



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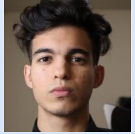
Technology	Operating Principle	Range
Ultrasonic (HC-SR04)	Emits 40 kHz sound pulses, measures echo return time	2 cm - 4 m
IR Reflectance	Measures reflected infrared intensity from target surface	1 - 30 cm
Time-of-Flight Laser (ToF) -- SELECTED	**940 nm laser pulse, measures photon round-trip time**	**1 mm - 2 m**

Why Time-of-Flight?
ToF was selected because it provides 1 mm accuracy across a 3–120 cm range using a 940 nm laser, ideal for detecting the 6.5" underbody clearance zone. Ultrasonic has poor angular resolution in a confined space, and IR Reflectance is limited to 30 cm and is sensitive to surface color and ambient IR noise.

Proximity Sensor: Part Selection



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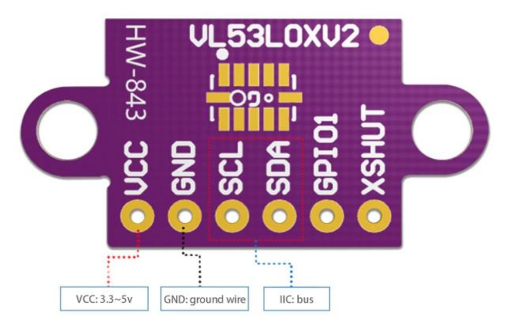
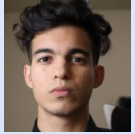
Part	Range	Interface	Accuracy
HC-SR04	2 – 400 cm	GPIO Trig/Echo	~3 mm
VL6180X	0 – 10 cm	I2C	1 mm
VL53L0X -- SELECTED	**3 – 120 cm**	**I2C 400 kHz**	**1 mm**



Actuator: Technology Comparison



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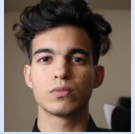
Technology	Motion Type	Control
Servo Motor	Rotary – limited to ~180 arc	PWM angle signal
Solenoid	Linear snap – binary extend/retract	On/Off GPIO
DC Linear Actuator -- SELECTED	**Direct linear extend and retract**	**PWM speed + DIR pin**

Why DC Linear Actuator?
A DC linear actuator provides direct linear motion without a mechanical linkage conversion, unlike servos which are rotary. Solenoids only support binary snap motion with no speed control. The linear actuator's PWM + DIR interface allows smooth speed ramping and position control via the Cytron MD10C driver.

Actuator: Part Selection



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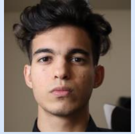
Part	Force	Feedback
uxcell 12V 50mm	~30 N	None
Actuonix L12-30-50-12-I	~45 N	Potentiometer
12V DC Linear Actuator 6 inches -- SELECTED	**~100 N**	**Hall Effect (internal)**

Motor Driver: Technology Comparison



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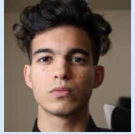
Switching Technology	How It Works	Speed Control
Bipolar H-Bridge (BJT)	NPN/PNP transistors switch current path through motor – base current drives collector current	PWM capable but 2V+ dropout across transistors wastes heat
Relay (mechanical switch)	Electromagnetic coil physically closes metal contacts to connect motor terminals	No PWM – contacts arc and weld at switching frequencies above ~10 Hz
MOSFET H-Bridge -- SELECTED	**N-channel MOSFETs switch with near-zero Rds-on resistance – very low voltage drop across switch**	**Full PWM at any frequency, sign-magnitude or locked-antiphase control modes**

Why MOSFET H-Bridge?
MOSFET H-Bridges have near-zero Rds-on resistance (≤50 mΩ), generating almost no heat at the currents required. BJT bridges waste 2V+ across transistors as heat. Relays cannot PWM above ~10 Hz without contact arcing. Only the MOSFET bridge supports full-speed PWM for smooth actuator control.

Motor Driver: Part Selection



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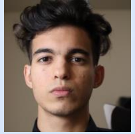
Part	Cont. Current	Voltage	Control Pins
L298N Module	2 A	5 – 35 V	3 pins: EN + IN1 + IN2
DRV8833 Module (TI)	1.5 A	2.7 – 10.8 V	2 pins: IN1 + IN2
Cytron MD10C -- SELECTED	**10 A continuous**	**5 – 30 V**	**2 pins: PWM + DIR**

Wheel Speed Sensing: Technology Comparison



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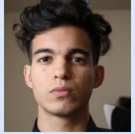
Technology	Principle	Output
Accelerometer	Measures rate of change of velocity (acceleration); speed is estimated by integrating over time	Analog/digital acceleration vector
Reed Switch	Magnet passing the switch pulls two ferromagnetic contacts together, closing the circuit	Mechanical contact closure
Digital Hall Effect Sensor -- SELECTED	**Magnet mounted on the wheel passes a solid-state sensor IC, which outputs a clean digital pulse with each pass**	**Digital pulse train**

Why Digital Hall Effect?
Accelerometers require integration over time to estimate speed, accumulating drift error. Reed switches are mechanical and prone to contact bounce and wear. A Hall effect sensor produces a clean digital pulse each time a wheel magnet passes, giving a precise, noise-free speed signal directly readable by GPIO interrupt.

Wheel Speed Sensor: Part Selection



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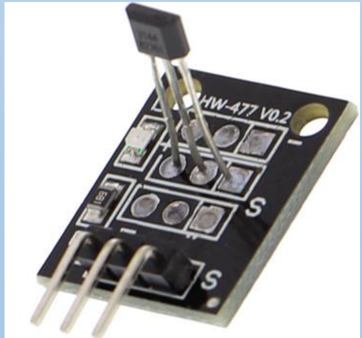
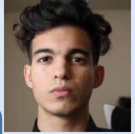
Part	Form Factor	Output	Supply
A3144 / A3144E	Bare TO-92 chip, no breakout board	Open-collector pulse	4.5 – 24 V
Honeywell SS441A	Bare TO-92 chip, no breakout board	Open-collector pulse	4.5 – 24 V
HW-477 V0.2 -- SELECTED	**Comparator breakout board: onboard LM393, trip-point trim pot, status LED**	**Digital pulse (TTL)**	**3.3 – 5 V**



Camera Node Compute: Technology Comparison



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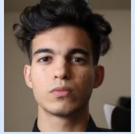
Technology	Capability	Wireless
MCU + Camera Module (e.g. ESP32 + OV2640)	Low-res JPEG capture, limited onboard processing	Native WiFi on some variants
Single-Board Computer (SBC) -- e.g. Raspberry Pi 4	**Full Linux OS, hardware-accelerated CSI camera pipeline, GPU video encode**	**USB WiFi dongle or onboard module depending on model**
Dedicated IP Camera Module (self-contained streaming camera)	Built-in encoder and streaming server, closed firmware	Built-in WiFi

Why Single-Board Computer (SBC)?
An MCU + camera module lacks the processing headroom for real-time H.264 encode and WiFi streaming simultaneously. Dedicated IP cameras use closed firmware, preventing custom NIR pipeline configuration. An SBC running Linux provides libcamera, hardware-accelerated CSI encoding, and open WiFi networking.

Camera Node Compute: Part Selection



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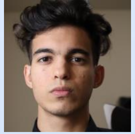
Part	CPU	RAM	CSI Support
Raspberry Pi Zero 2 W	Quad-core Cortex-A53 @ 1 GHz	512 MB	Single CSI lane, mini connector
Raspberry Pi 3 Model B+	Quad-core Cortex-A53 @ 1.4 GHz	1 GB	Single CSI lane
Raspberry Pi 4 Model B -- SELECTED	**Quad-core Cortex-A72 @ 1.5 GHz**	**2-4 GB**	**Full CSI-2 lane, native libcamera support**

MCU Technology Comparison



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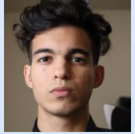
MCU Family	Architecture	Wireless
ARM Cortex-M4 (e.g. STM32F4 series)	32-bit, higher per-clock performance, rich peripheral set	None onboard – requires external WiFi module (e.g. ESP8266, ATWINC1500)
8-bit AVR (e.g. ATmega328P / Arduino Uno)	8-bit, 20 MHz max clock, extremely well documented	None – no wireless capability whatsoever
Dual-core Xtensa LX6/LX7 (Espressif ESP32 family) -- SELECTED	**32-bit dual-core, up to 240 MHz, hardware FPU, multiple timers, up to 34 GPIO**	**Integrated 2.4 GHz WiFi + BLE – no external module needed**

Why ESP32 Family?
STM32 requires an external WiFi module, adding PCB complexity and cost. The 8-bit AVR has no wireless capability at all. The ESP32 integrates dual-core 240 MHz processing, WiFi + BLE, and rich peripherals (I^2C, UART, PWM, GPIO) on a single chip, covering every AURA interface requirement without add-ons.

MCU Part Selection



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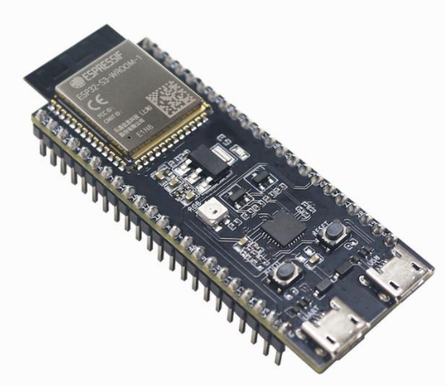
Part	Core / Clock	Memory	Wireless
ESP32-WROOM-1U (ESP32-D0WD-V3)	Dual 240 MHz LX6	4 MB flash, 520 KB SRAM, no PSRAM	WiFi + BT/BLE, U.FL external antenna
Nordic nRF52840	Single 64 MHz Cortex-M4	1 MB flash, 256 KB RAM	BLE, Thread, Zigbee – no native WiFi
ESP32-S3 Dev Board (ESP-1-N16R8) -- SELECTED	**Dual 240 MHz LX7**	**16 MB flash, 8 MB OPI PSRAM**	**WiFi + BLE 5.0, native USB**



High-Frequency Alarm

Christopher Nunez-Velasquez
Electrical Engineer

Technology	Cost	Output Strength	Range
Ultrasonic Tweeter Speakers	Moderate	Moderate	Short
Magneto strictive Transducers	High	Very High	Long
Piezoelectric Transducers	Low	High	Moderate

Why Piezoelectric Transducers?
Low cost with high SPL output (120 dB) at the drive voltage our circuit already produces. Magnetostrictive transducers are far more expensive with no benefit at short underbody range. Tweeter speakers lack sufficient output strength for reliable animal deterrence.

Ultrasonic Transducers

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Component	SPL	Beam Angle	Voltage Rating
40 kHz Transducer			
CUSA-T80-15-2400-TH	105 dB	80°	80 V_{p-p}
CUSA-T80-18-2400-TH	115 dB	80°	150 V_{p-p}
MA40S4S	120 dB	80°	24 V_{p-p}
30.5 kHz Transducer			
CUSA-T75-120-2200-W	105 dB	75°	160 V_{p-p}
CUSA-T80-120-2200-W	100 dB	80°	160 V_{p-p}
CUSA-T80-130-3000-TH	120 dB	80°	200 V_{p-p}

Motor Interlock

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Electrical Engineer

Technology	Functionality	Reliability	Complexity
Relay Module	ON/OFF	Moderate	Low-Moderate
Motor Driver	PWM	Moderate	High
Automotive Relay	ON/OFF	High	Low

Why Automotive Relay?
A standard relay module lacks the contact rating for the ride-on car's 12V drive motor current. A motor driver adds unnecessary PWM complexity for a simple ON/OFF interlock. An automotive relay provides high contact ratings (40–70 A), proven reliability, and simple GPIO-controlled coil activation.

Automotive Relay

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Component	Contact Rating	Operate/Release Time	Switching Voltage
CB1AHF-R-24V	70 A	15 ms	14 VDC
3-1415001-2	70 A	7ms/2ms	12 VDC
JD1912	40 A	15 ms	12 VDC

Regulators

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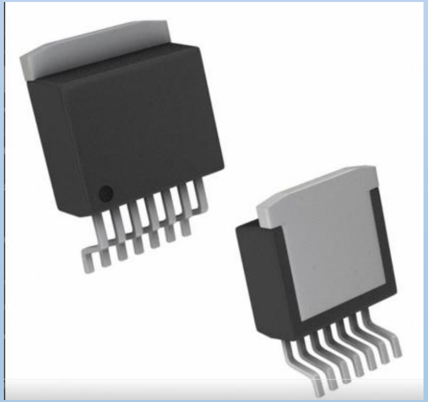
Electrical Engineer

Component	Output Current	Min/Max Input Voltage	Min/Max Output voltage
AP64501	5A	3.8/40V	0.8/39V
LM2575	2A	4.75/40V	1.2/37V
LM2679	3A-7A	8/40V	1.2/37V

Why LM2575?
Supplies up to 5A, more than enough headroom for our 3.3V and 5V rails, and to ensure sufficient powering to the PIs. Also the part Dr. Weeks recommended directly.



Estimated Peak Power Budget

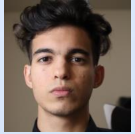


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Table 3.2.10.3.A: A.U.R.A. Estimated Peak Power Budget

Component	Supply Voltage	Est. Current Draw	Est. Power	Notes
Raspberry Pi 5	5 V	2,500 mA (peak)	12.5 W	Central processing node; runs YOLOv11 detection
Raspberry Pi 4 (x2)	5.1 V	3,000 mA total	15.3 W	Camera nodes; 1.5 A each typical, 3 A peak combined
ESP32-S3 (x3)	3.3 V	240 mA total	0.8 W	MCU per camera node; WiFi + sensor I/O
NIR LED Array (x2 modules)	12 V	500 mA total	6.0 W	940 nm illumination; MOSFET-switched, 180 Ω current-limit resistors
Linear Actuators (x2, peak)	12 V	1,000 mA total	12.0 W	Peak stall current; typical run ~500 mA total
Cytron Motor Drivers (x2)	12 V	200 mA idle	2.4 W	MD10C; 10 A continuous capacity, idle draw shown
LCD Dashboard (7 inch)	5 V	800 mA	4.0 W	Driver status display
Sensors, Relay, Misc.	3.3–5 V	~200 mA	~1.0 W	VL53L0X ToF, HW-477 Hall effect, automotive relay coil
Total Estimated Peak				~54.0 W estimated peak (all subsystems simultaneous)

Power Supply

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Technology	Main Strength	Main Limitation	Suitability
Sealed Lead-Acid (SLA)	Low cost, simple integration	Heavy, low cycle life	Not ideal for compact system
Lithium-Ion (Li-ion)	High energy density, lightweight	Safety concerns, complex BMS	Good but riskier
Lithium Iron Phosphate (LiFePO4)	High safety, long cycle life, stable voltage	Higher cost	Best overall fit

Why LiFePO4?
SLA batteries are too heavy for a small ride-on vehicle and have poor cycle life. Li-ion packs require a complex BMS and carry thermal runaway risk. LiFePO4 offers stable voltage, 2000+ cycle life, and inherent thermal safety, the best balance of safety, weight, and longevity for a demo vehicle application.

Battery

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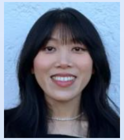
Component			
12V SLA Battery	12V	Low cost, easy to source	Heavy, shorter lifespan
3S Li-ion Pack	11.1V	Lightweight, compact	Requires protection circuitry
12.8V LiFePO4 Pack	12.8V	Safe, long cycle life, stable output	Higher upfront cost

Imaging System Selection Summary



Theresa Dinh
Optics and Photonics

Component/Part	Options compared	Selected	Reasoning
Optical Configuration	Spherical Wide-Angle Lens Fisheye Lens Dual-Lens 360 Camera Anamorphic Prism System Cylindrical Anamorphic Galilean System Cylindrical Anamorphic Inverse Galilean System	Cylindrical Anamorphic Inverse Galilean System	Compact and directly matched to the required field compression
Spectral Band	Visible (400-700 nm) NIR (700-1000 nm) SWIR (900-1700 nm) LWIR (Thermal)	NIR	Works with low-cost silicon sensors and controlled illumination
Sensor	Seeed IMX219 Raspberry Pi HQ Camera with IMX477 Raspberry Pi Camera Module 3 NoIR Arducam OV9281 Global-Shutter Module Sony IMX178 (Mono) Module	Sony IMX178	Large sensor format to accommodate anamorphic mapping, superior low-light sensitivity, and flexible C/CS lens compatibility

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Electrical Engineer

Hardware Design

Main PCB Schematic

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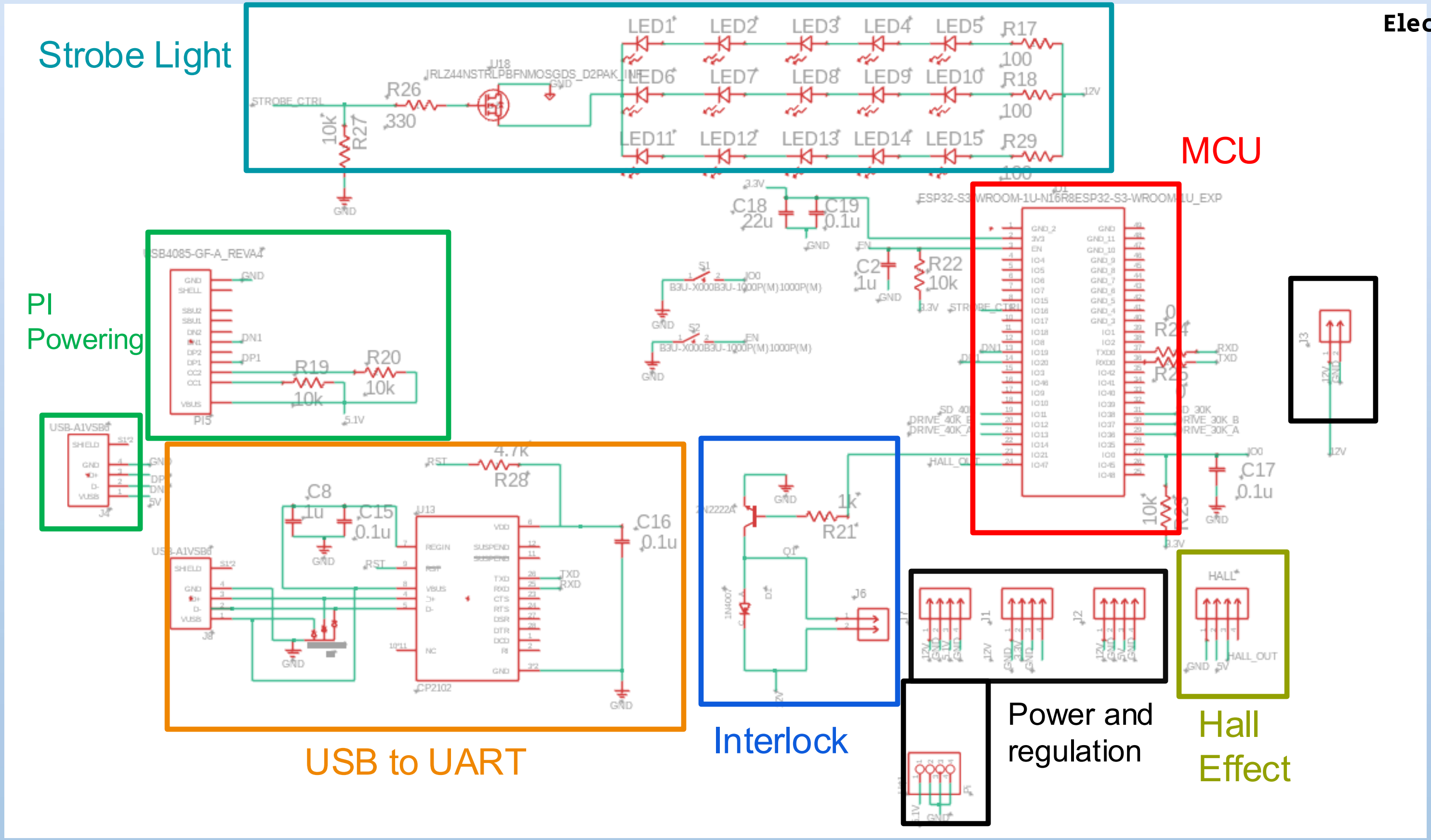
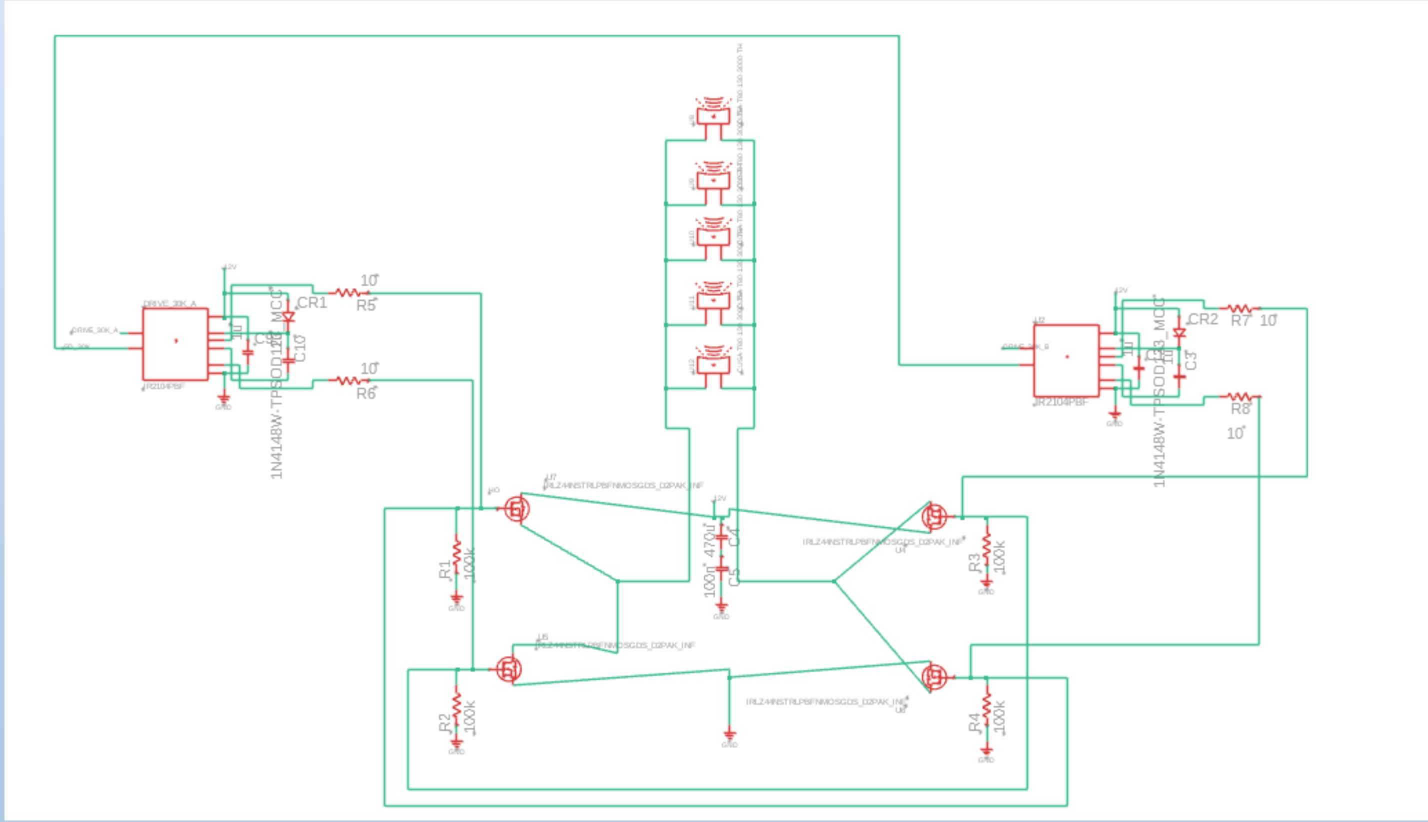
Electrical Engineer

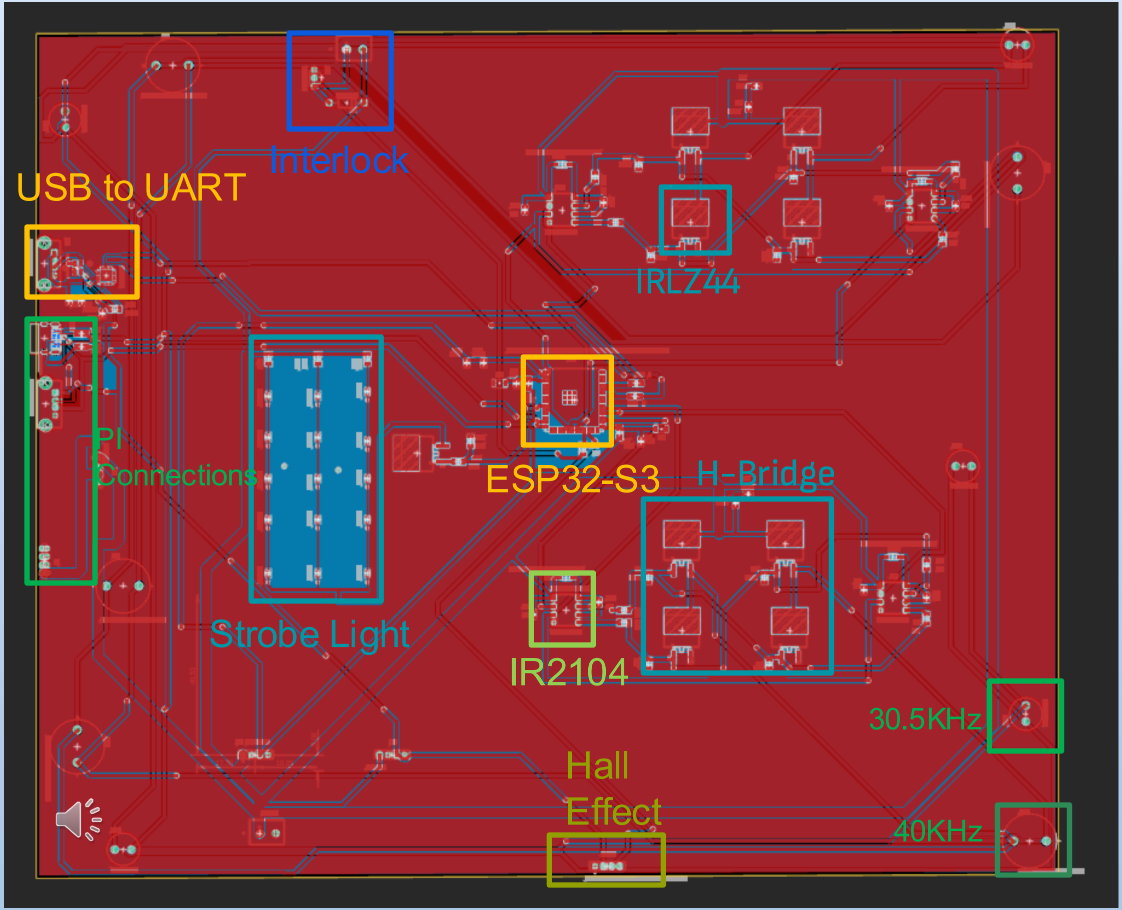


Main PCB Schematic (Ultrasonic Alarms)

Christopher Nunez-Velasquez
Electrical Engineer



Main PCB Layout



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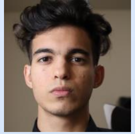
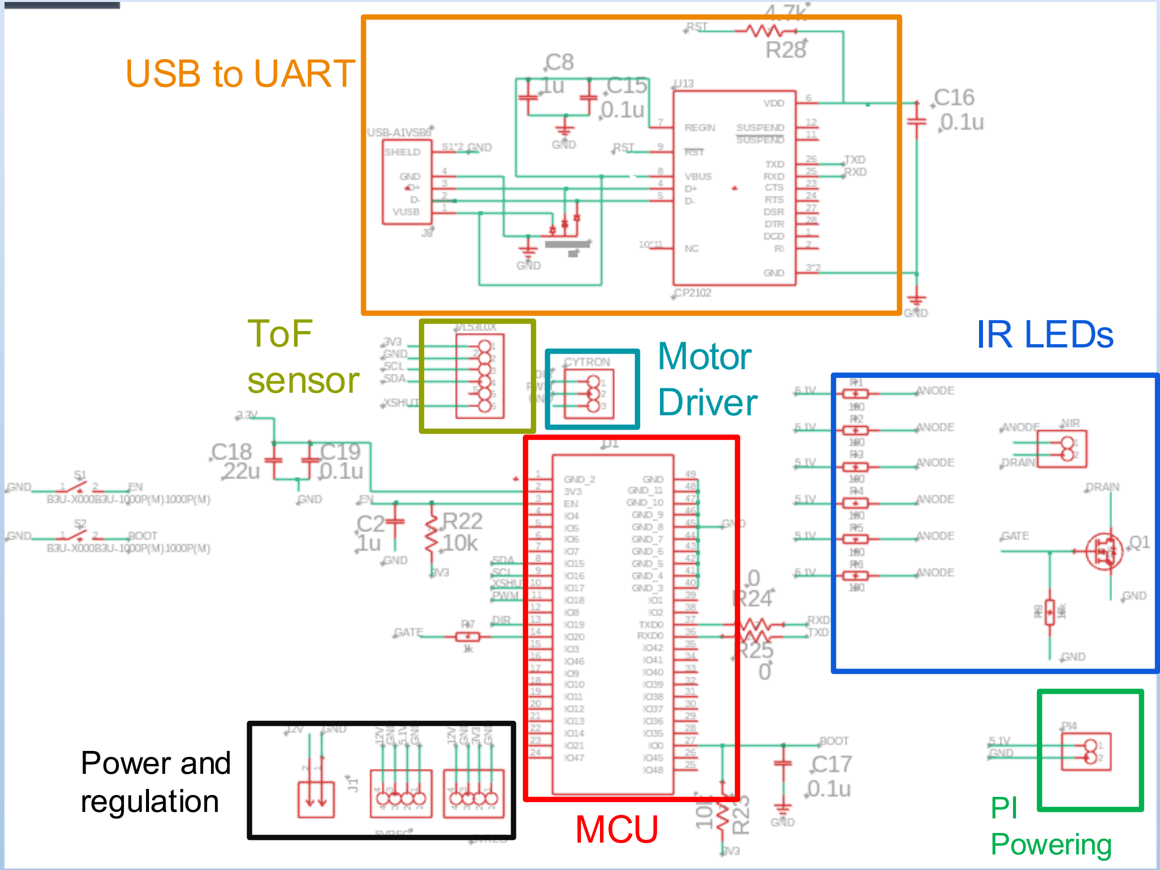
Electrical Engineer

- Transducers – On outer edges for directionality outwards
- Voltage input, USB ports, hall-effect sensor, and motor interlock – On outer edge for accessibility
- MCU – Positioned at center
- LED array – near center for strobe coverage
- H-Bridge amplifiers – Opposite ends of most peripherals for better spacing
- Regulators- Near Voltage input

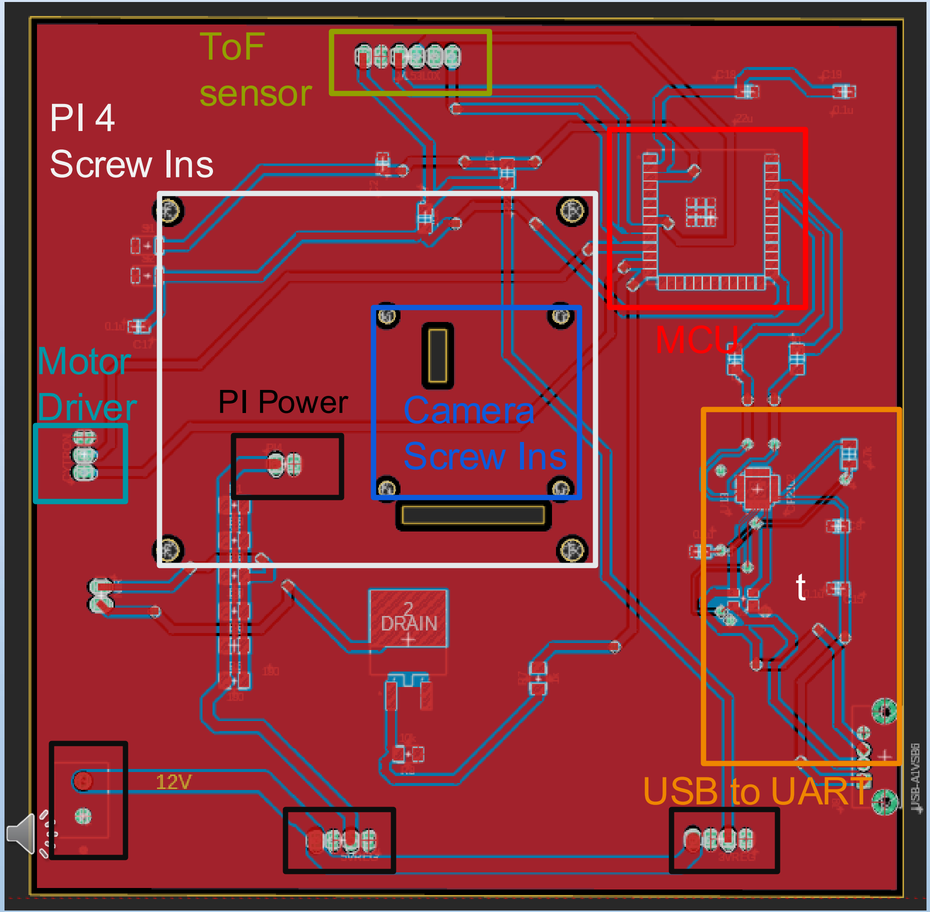
Secondary PCB Schematic

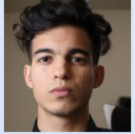


Oussama Benamar Hlimi
Electrical Engineer



Secondary PCB Layout

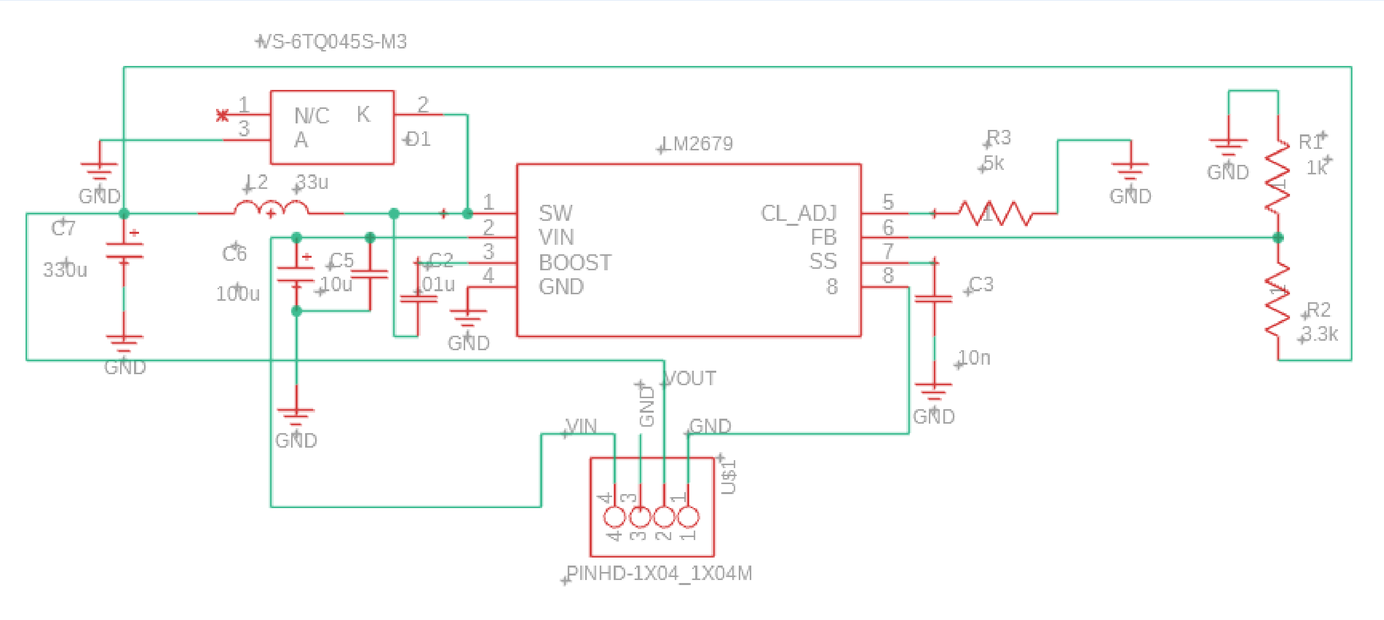




Oussama Benamar Hlimi
Electrical Engineer

- ToF sensor, at the edge of the board for easy reach to tip of actuation
- Motor Driver pins at edge for motor driver board to be separate and under chassis of car.
- Screw ins for Pi 4 to be positioned under the board, and for camera to be centered.
- MCU – to the side
- Regulators- Near Voltage input

Regulator PCB Schematic



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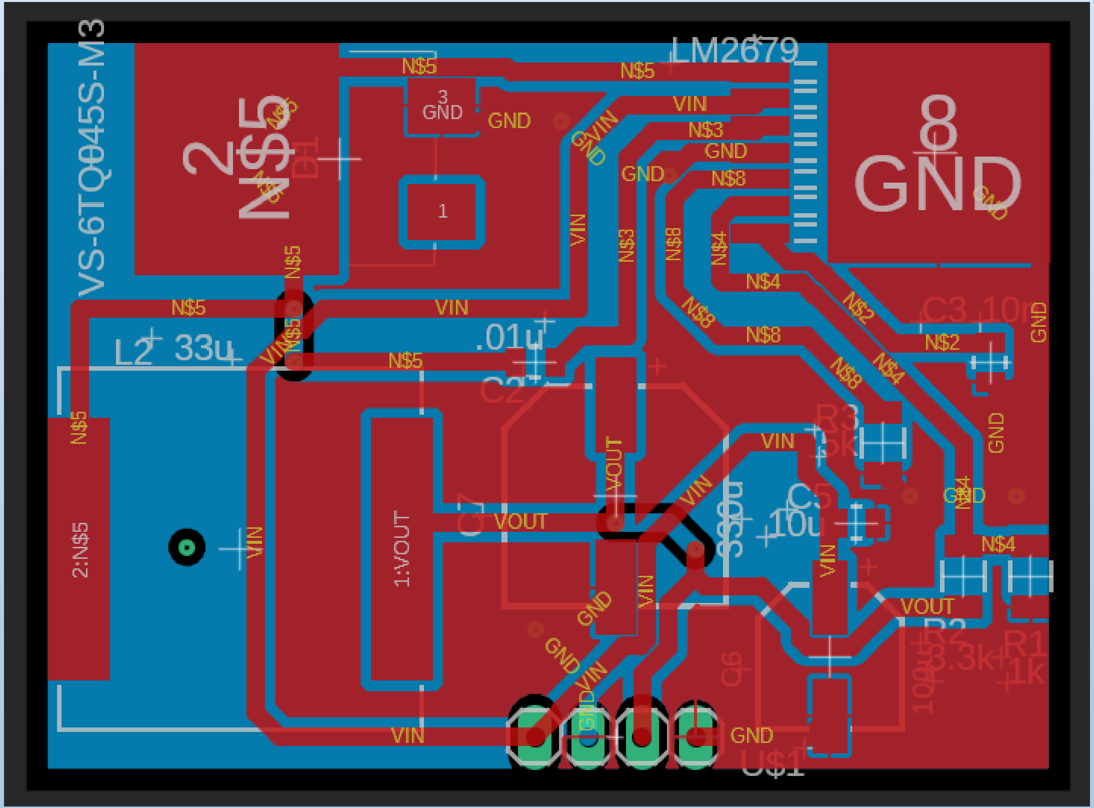
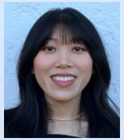
Regulator PCB Layout



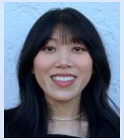
Christopher Nunez-Velasquez
Electrical Engineer

Optical Limitation: Extreme FOV Geometry



Theresa Dinh
Optics and Photonics

- Scene geometry is wide HFOV + moderate VFOV
  - Wheel track: 23”
  - Clearance: 4.5-7.5”
  - Stand-off Distance (D): 6”
- Required Angular Coverage
  - $FOV = 2 \tan^{-1}(dimension/(2D))$
  - HFOV = 121°, VFOV = 44.3°
  - Angular Ratio = 2.73:1

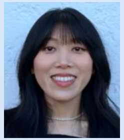


Theresa Dinh
Optics and Photonics

Optical Component Specifications

Component	Parameter	Description	Target Value and Unit(s)
Anamorphic Lens System	Field of View (Demo)	The front/rear lenses must cover the entire width and length of the undercarriage of a demonstration vehicle with 23″ wheel track and 4.5″-7.5″ clearance.	121° (H) x 45° (V)
	Field of View (Scalable)	The front/rear lenses must cover the entire width and length of the undercarriage of a full-sized AV with 64.7″ wheel track and 6.5″ clearance.	Up to 157.3° (H) x 53.1° (V)
	Squeeze Factor (Demo)	Required horizontal angular compression to match the IMX178 active-area aspect ratio (7.41×4.95 mm) for demo vehicle.	1.82x
	Squeeze Factor (Scalable)	Required horizontal angular compression to match sensor aspect ratio for full-sized AV.	1.98x
System Geometry	Scene Ratio (Demo)	Linear aspect ratio of the physical target window (Width/Height) for the demo vehicle.	4.35:1
	Scene Ratio (Scalable)	Linear aspect ratio of the physical target window for full-sized AV.	9.95:1
NIR Filter	Bandwidth	Selective spectral gating to block non-NIR solar and ambient noise.	10 nm FWHM @850 nm
Objective Lens	Focal Length	To ensure that the VFOV fits the sensor's height.	3.0-3.2 mm
Imaging System	Effective Resolution	Resolves biological targets beneath the demo vehicle. Scalable platform may require a higher resolution sensor	≥ 3 px/mm at ground plane

Optical Design



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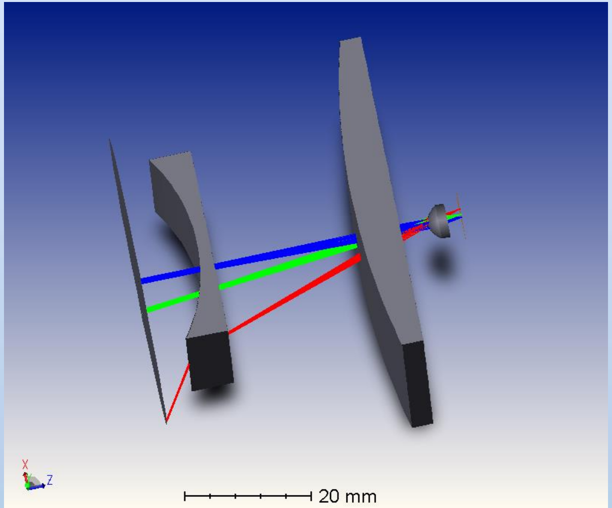
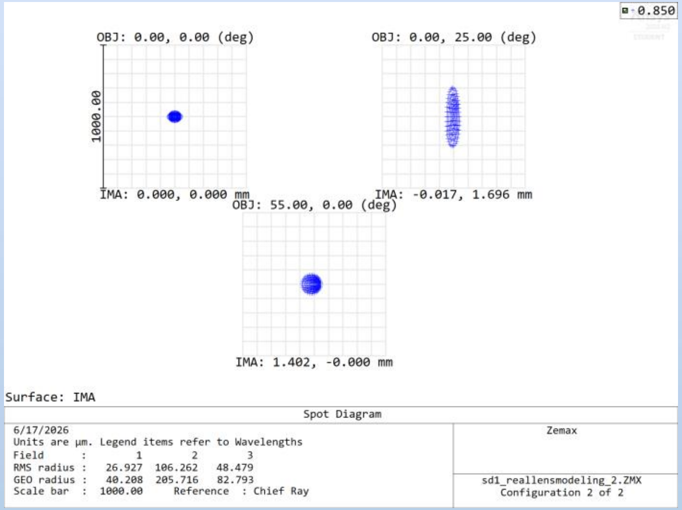
Optics and Photonics





- 3D Modeled Lens System
  - Has a field of 55° HFOV and 25° VFOV (half-angle)
  - Plano-concave + Plano-convex Cylindrical Pair
  - Note: Replaced initial plano-convex lens for a bigger one

- Spot Diagram
  - Optimized Horizontal Field
  - Astigmatism in Vertical Field

Communications Protocol and Data Flow

Kimberly Lugo
Computer Engineer

Link	Protocol	Purpose	Reasoning
Pi 4B camera nodes → Main Pi 5	Wi-Fi	Send camera frames/stream data	Reduces wiring between front and rear modules
Main Pi 5 → ESP32 safety controller	Wi-Fi	Send hazard, clear, and fault commands	Simple, direct, low-overhead control link
ESP32 → Main Pi 5	Wi-Fi	Send ACK/status response	Confirms command was received

- Wireless link reduces long camera wiring
- Camera streams and safety commands use separate network connections
- Pi 5 acts as the central decision point
- Wi-Fi carries camera data, safety commands, and acknowledgments

Software Selection Summary

Software area	Options compared	Selected	Reasoning
Platform / OS	Bare-metal RTOS Embedded Linux	Raspberry Pi OS / Embedded Linux	Camera drivers, networking, OpenCV, Python, and ML libraries are supported
Imaging Processing	OpenCV scikit-image Pillow	OpenCV	Real-time frame resizing, filtering, contrast adjustment, and camera pipeline tools
Detection	YOLO MobileNet SSD Haar Cascade	YOLOv11 Nano	Best speed-to-accuracy tradeoff for embedded animal detection
Language / framework	Python C++ ROS Standard Python ROS Python Modular Python	Python / Standard Python	Integrates with OpenCV/YOLO while avoiding extra ROS complexity

Kimberly Lugo
Computer Engineer

- **Full stack supports camera input and ML**
- **Embedded Linux simplifies driver support**
- **OpenCV supports real-time preprocessing**
- **Python keeps development practical**
- **Standard Python avoids ROS overhead**

Vision and Detection Selection

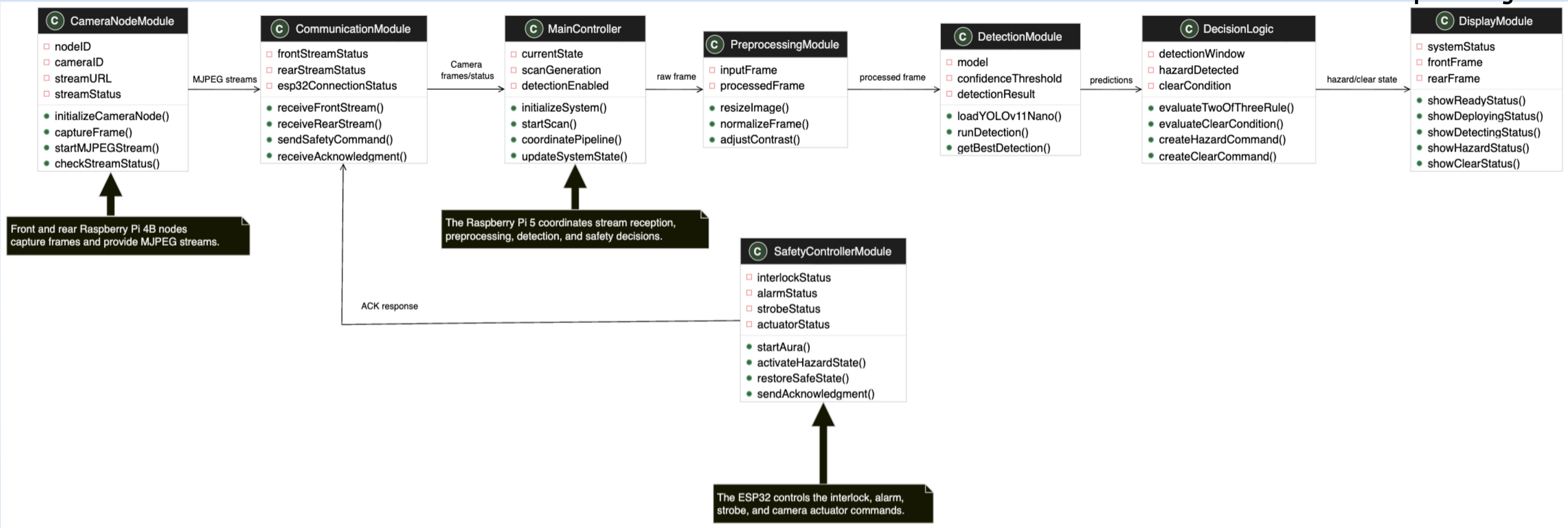
Decision area	Options compared	Selected	Reasoning
Detection Technology	YOLO Mobile-Net SSD Haar Cascade	YOLO-based detection	Fast enough for the startup safety window while maintaining useful detection accuracy
Detection Model	YOLOv5 YOLOv8 YOLOv11	YOLOv11 Nano	Lower latency on embedded hardware with enough performance for demo-level detection
Dataset Workflow	LabelImg Roboflow	Roboflow	Integrated labeling, preprocessing, augmentation, and training platform

Kimberly Lugo
Computer Engineer

- YOLO balances speed and accuracy
- YOLOv11 Nano supports embedded detection
- Roboflow organizes training workflow
- Dataset must match underbody views

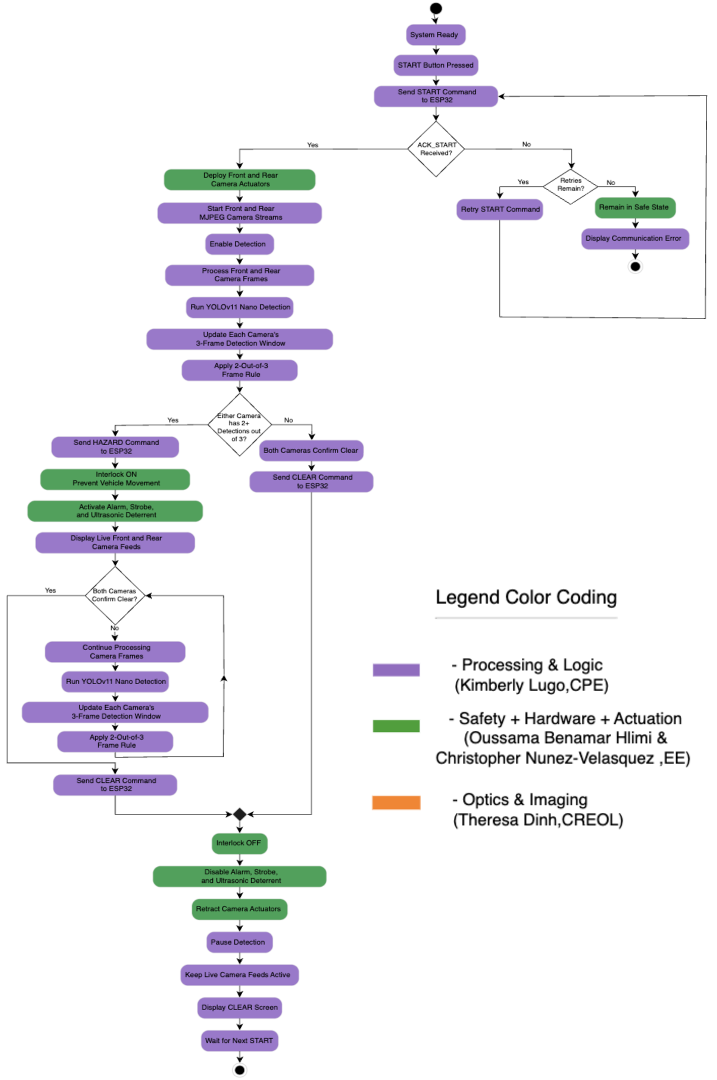
Software Module Structure

Kimberly Lugo
Computer Engineer



- Camera nodes provide front and rear MJPEG streams
- Pi 5 coordinates processing and detection
- YOLOv11 Nano evaluates incoming frames
- Decision logic converts detections into safety commands
- ESP32 controls interlock, alerts, and actuators
- Wi-Fi/TCP carries commands and acknowledgments

Software System Flowchart



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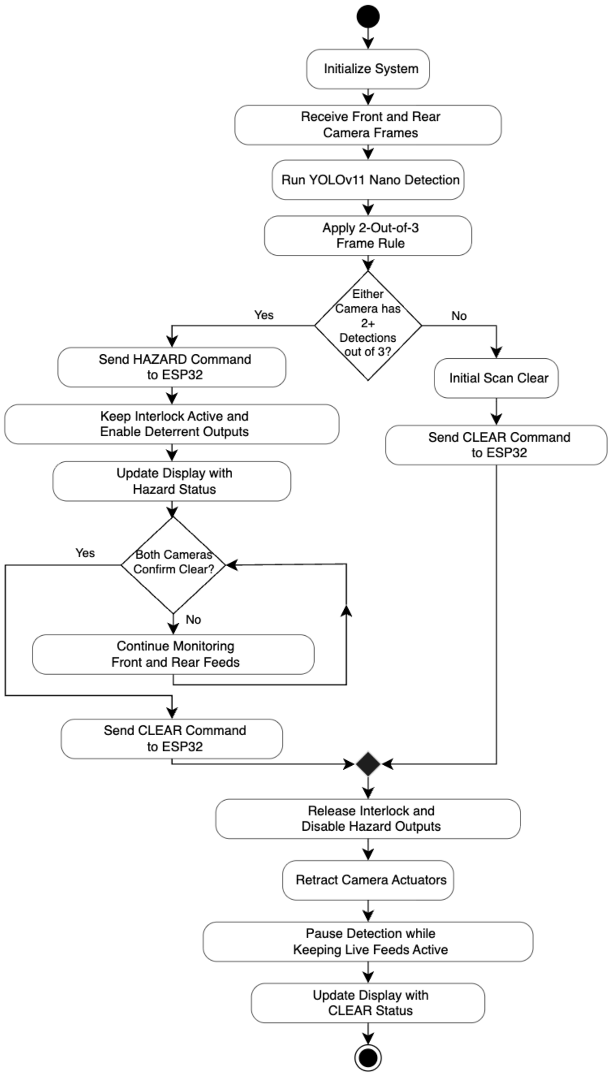
Computer Engineer

- START command begins camera actuator deployment
- YOLOv11 Nano processes front and rear camera frames
- Hazard requires detection in at least 2 of 3 frames
- Hazard response remains active until both cameras confirm clear
- CLEAR pauses detection while live camera feeds remain active

Startup Safety Logic

- YOLOv11 Nano analyzes both camera feeds
- Hazard requires detection in at least 2 of 3 frames
- Either camera can trigger the hazard response
- Both cameras must confirm clear before release
- CLEAR pauses detection while live feed remain active



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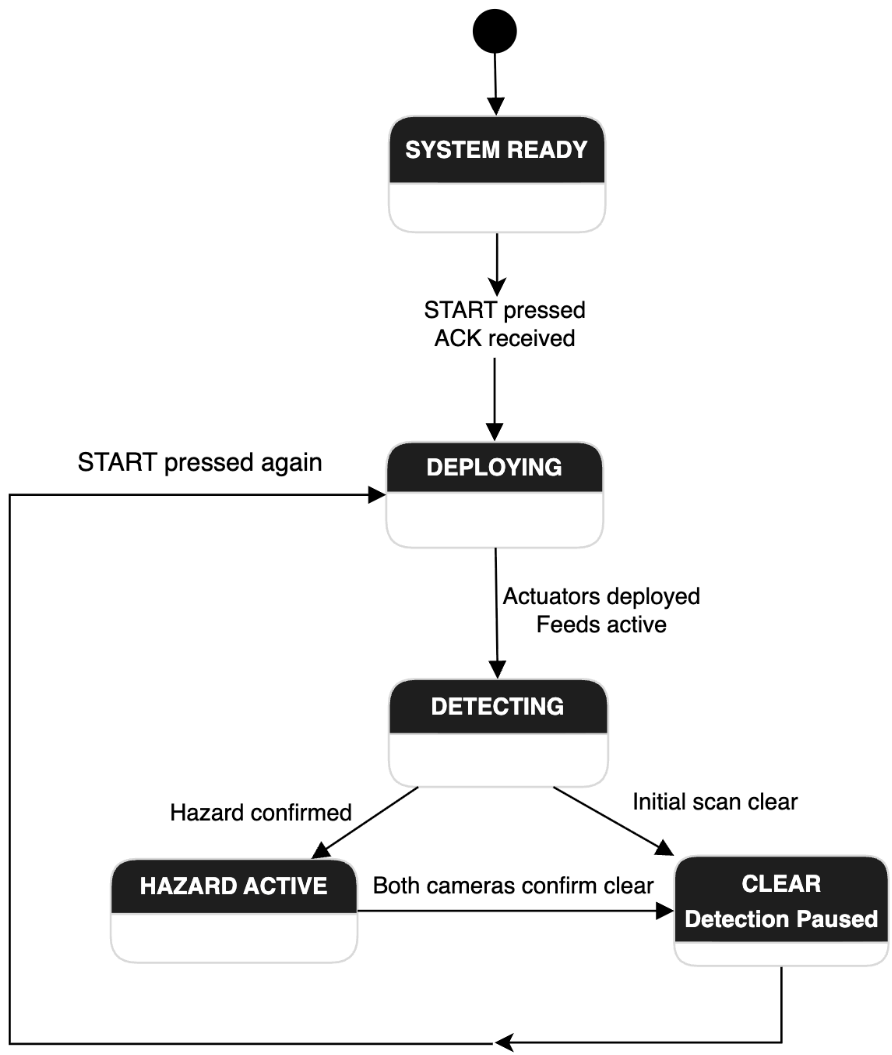
Software Safety State Diagram

- States represent the main operating modes
- Transitions occur after confirmed events
- Hazard remains active until clear is verified
- START begins a new monitoring cycle



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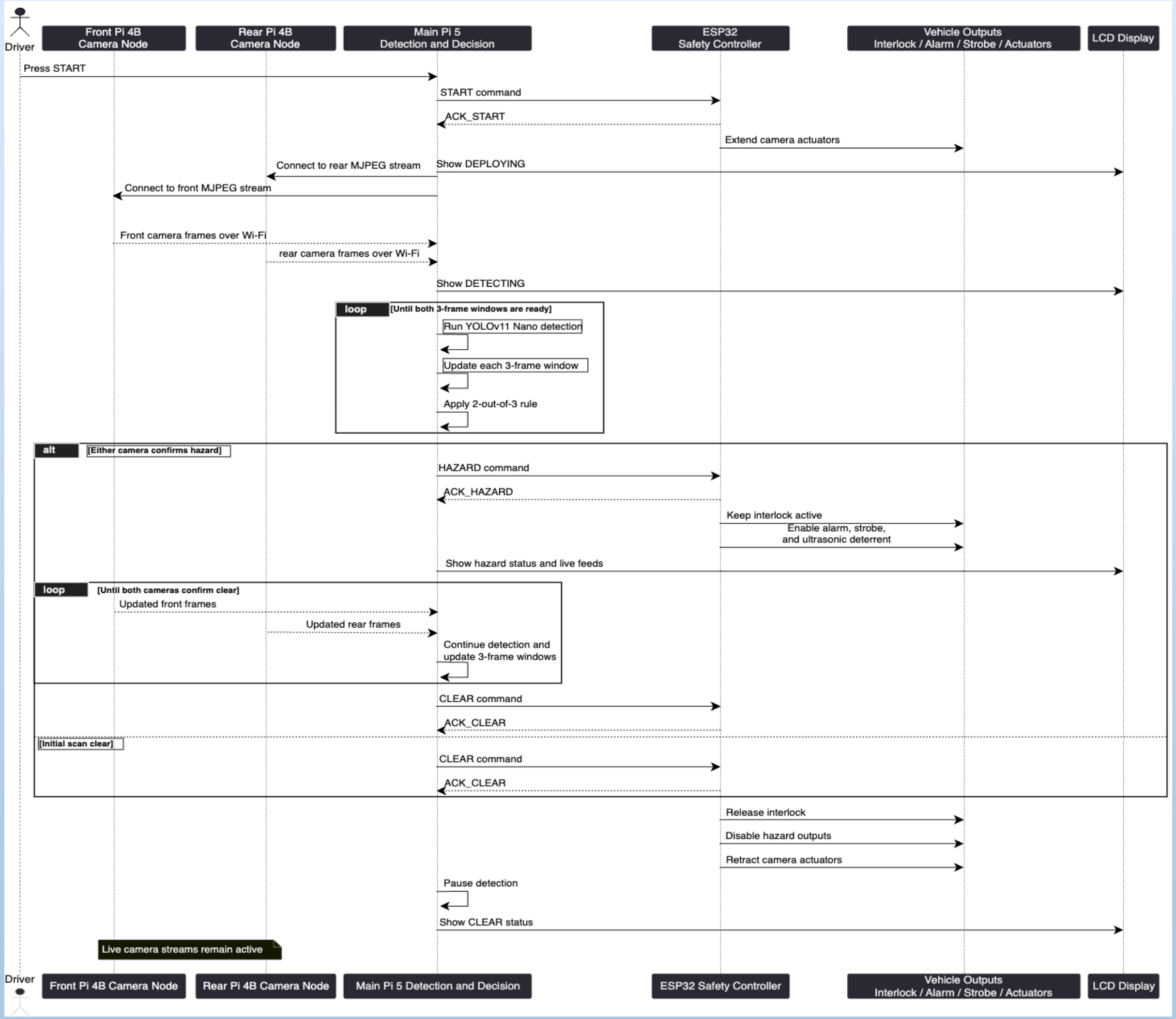
Computer Engineer

Software Sequence

- Pi 5 receives both camera streams over Wi-Fi
- Detection results determine HAZARD or CLEAR
- Safety commands are acknowledged by the ESP32
- ESP32 controls the physical safety outputs
- LCD displays current system state



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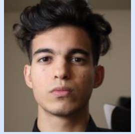


Oussama Benamar Hlimi
Electrical Engineer

Testing

Testing: Key Specifications

Christopher Nunez-Velasquez
Electrical Engineer

Test Setup : Actuation and Sensors

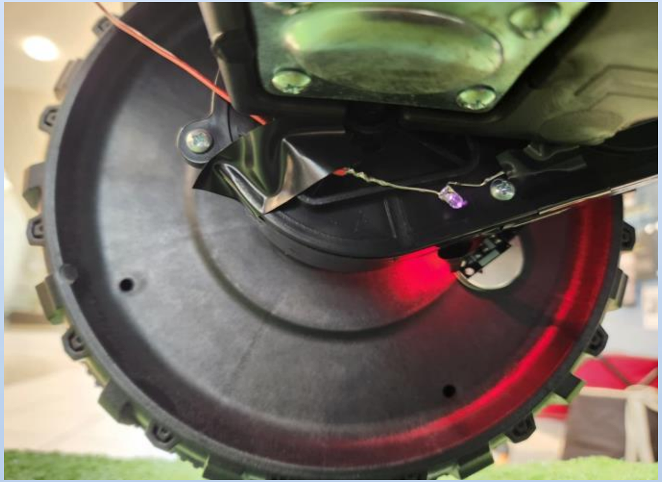
The linear actuator was powered from the 12V bench supply through the Cytron MD10C motor driver. The VL53L0X ToF sensor was mounted at the actuator tip and polled over I^2C. A target object was placed at a fixed 15 cm distance. The system was commanded to extend until the sensor read below the 20 cm threshold, then retract. Multiple runs were performed to verify consistent behavior and measure deployment time to confirm the less than 6 second deployment specification..

Test Setup : Motor Interlock

The automotive relay was wired in series with the ride-on car's drive motor power line. The ESP32-S3 GPIO was used to energize/de-energize the relay coil. A detection signal from our Raspberry PI5 was sent to the main board to open the relay. Result: relay opened within measured latency, confirmed by motor stopping and relay click. Tested across 10 consecutive trigger events with 100% success rate.

Test Setup : Hall-effect Sensor Actuator Retraction

The Hall-effect sensor was placed near one of the rear wheels; due to its low range it needed to placed relatively close to the magnet. The magnet was place on the rear wheel; by measuring the diameter of the wheel, the diameter of the magnet, and the distance of the magnet from the center of the wheel, the speed of the vehicle was calculated each time a magnet pulse was sensed by the hall-effect sensor. The speed of the wheel would then be sent to the serial monitor to be read; the speed was tested at three different speeds configurable by our vehicle. Each time the vehicle's speed was greater than the 1 MPH threshold, the actuators would retract.



Hall-effect and Magnet Placement

Testing: High Frequency Alarm

Ultrasonic Alarm	Input Frequency	Output Frequency	Vpp Out
30.5 kHz	30.5 kHz	31.24 kHz	26.367 Vpp
40 kHz	40 kHz	39.99 kHz	27.148 Vpp

- Yellow Signal - CH1
- Green Signal - CH2
- Blue Signal - Math Function (CH1-CH2)
- Probes used may have caused expected and observed values to differ.
- CH1 and CH2 180° out of phase

Christopher Nunez-Velasquez
Electrical Engineer

30.5 kHz Output

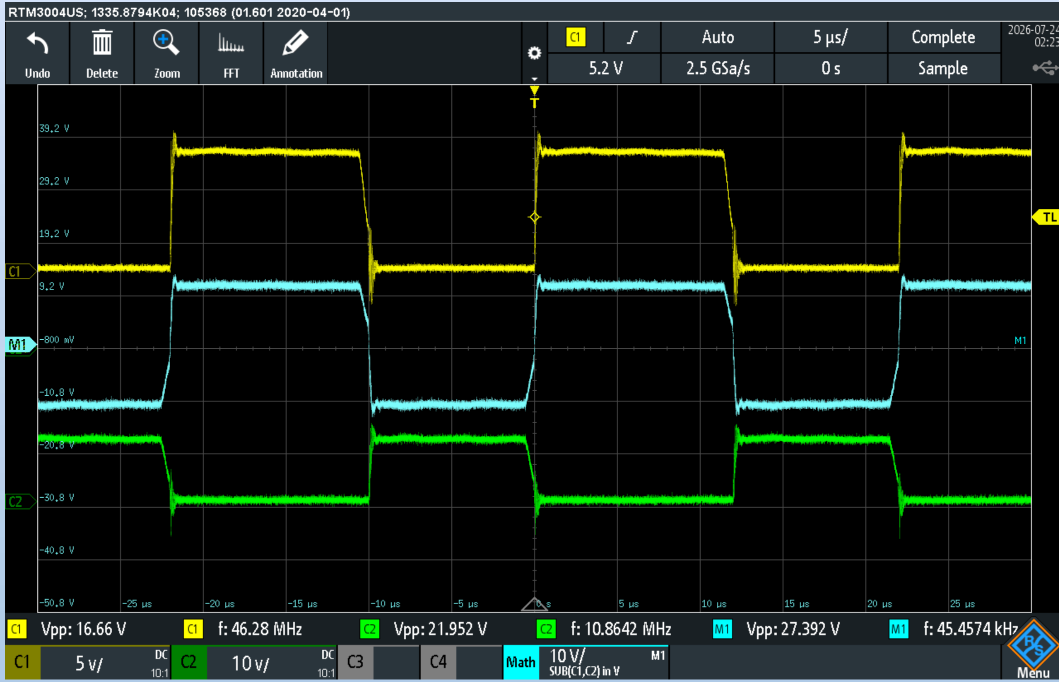
40 kHz Output

Testing: High Frequency Alarm

Christopher Nunez-Velasquez
Electrical Engineer

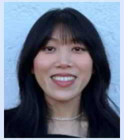
Ultrasonic Alarm	Input Frequency	Output Frequency	Vpp Out
45 kHz	45 kHz	45.457 kHz	27.392 Vpp

- 30 kHz – 45 kHz covers specification
- Spike at the beginning of each pulse caused by switching of MOSFETs

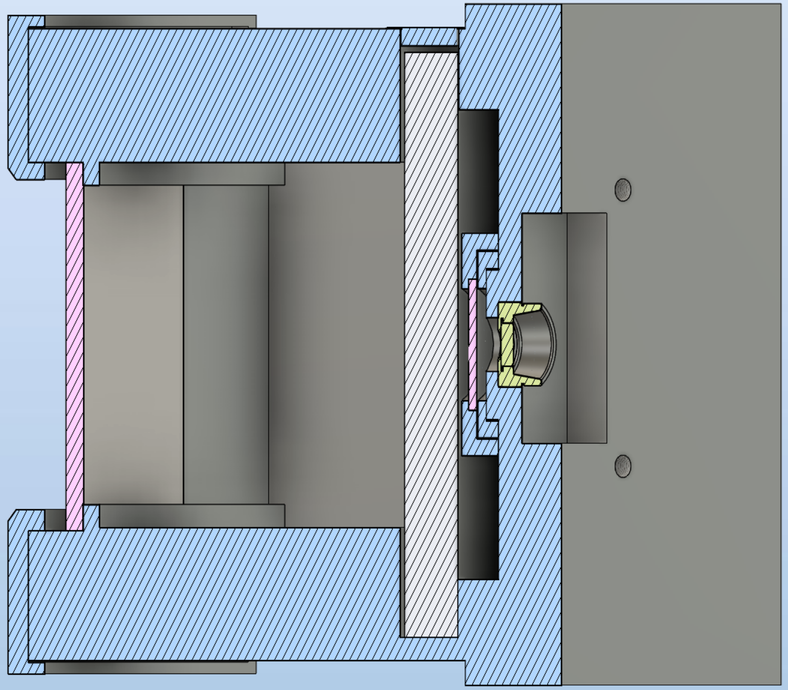


45 kHz Output

Optomechanical Design: Lens Housing

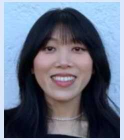


Theresa Dinh
Optics and Photonics



- Designed prototype housing
  - Holds negative cylindrical lens, positive cylindrical lens, bandpass filter, and objective + sensor mounted directly to housing
  - Spacing of lenses built in and designed to prevent elements from falling out

Prototyping and Testing: Imaging Performance



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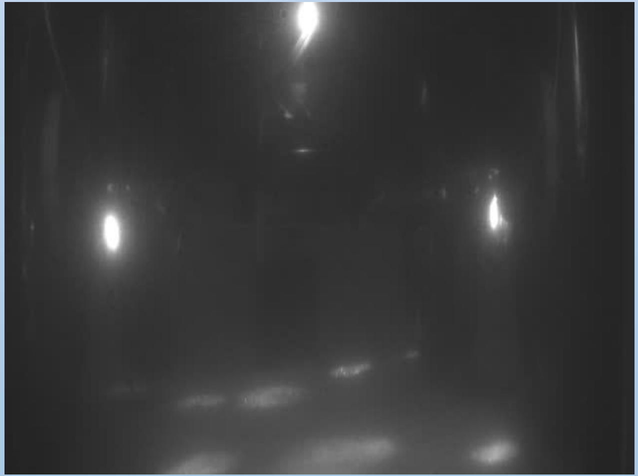
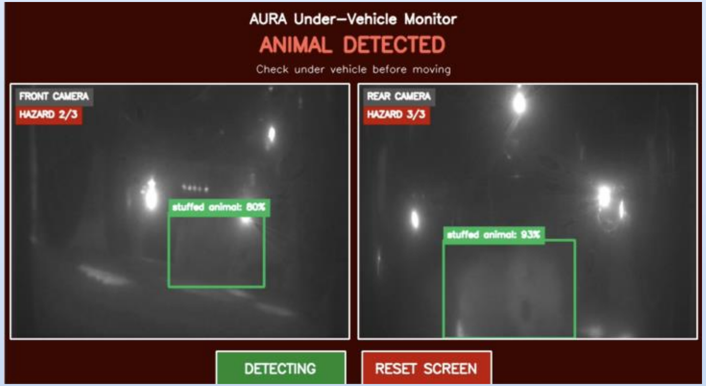
Optics and Photonics

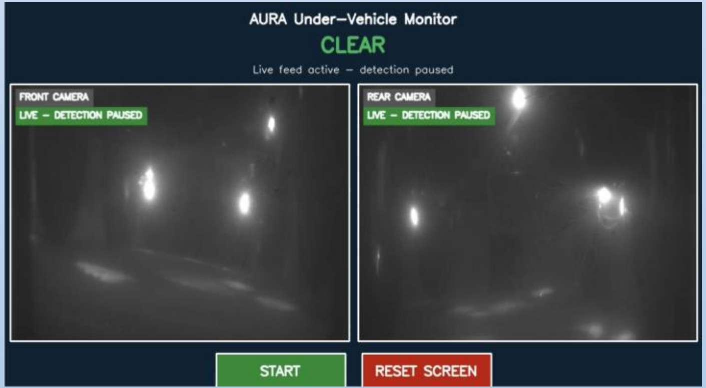
- Grid Subject (at 6 inch working distance)
  - Piece of paper (11" W x 8.5" H) with 1.0" W x 0.5" H grid lines (105 W x 86 H pixels measured at center grid box)
  - Measured Resolution: 4.13 px/mm (calculated from 105 pixels per 25.4 mm horizontal reference)
  - Measured Scene Ratio: 2.45:1 (29.41" W / 12.00" H physical target window scaled to full sensor layout)
  - Measured Squeeze Factor: 1.64x horizontal angular compression (2.45 Scene Ratio / 1.50 Sensor Aspect Ratio)

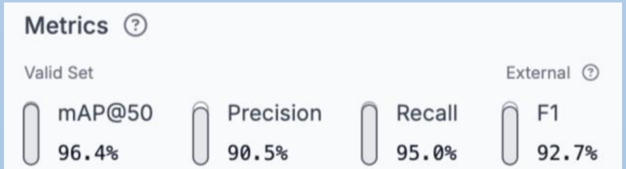
- NIR Illuminated Stuffed Animal (Under Demo Vehicle)
  - Stuffed animal target placed at the center underneath demo vehicle
  - Active 850 nm NIR illumination array
  - Identified optical blooming and pixel saturation across active light sources and highly reflective surfaces

Software Testing









Kimberly Lugo
Computer Engineer

- Underbody detection example shown
- Raw test scene shows difficult view
- Metrics summarizes validation results

Oussama Benamar Hlimi
Electrical Engineer

Difficulties, Problems & Solutions

Power & Regulation Challenges

Christopher Nunez-Velasquez
Electrical Engineer

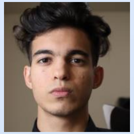
- **Pi 5 Regulator Shorting the Main Board**
  - The USB-C footprint on the main PCB was shorting to the board, and the Pi 5 regulator ended up frying the MCU
  - The Pi 5 was originally meant to talk to the main board over a wired link through that connector
  - Solution: dropped the wired link and moved Pi <-< main-board communication to wireless (Wi-Fi / ESP-NOW)
- **Regulator Could Not Supply Full Pi Current**
  - The single SMD bypass capacitor sat too far from the regulator, so it could not hold up 5 A when the Pi drew max current
  - Solution: soldered a capacitor directly onto the regulator’s legs so it sits close enough to stabilize the rail

Motor Driver & MCU Challenges

Christopher Nunez-Velasquez
Electrical Engineer

- **H-Bridge Troubleshooting / Repeated MCU Failures**
  - The driver stage took a very long time to troubleshoot
  - The schematic was slightly off, and MOSFETs and drivers kept failing, which also killed MCUs in the process
  - Solution: corrected the schematic, replaced the damaged MOSFETs and drivers, and re-tested until the stage was stable
- **MCU Not Grounded on the Main PCB**
  - Schematic oversight – the MCU ground pin was never routed to GND in Fusion
  - Solution: caught during bring-up and fixed with a ground jumper, then corrected in the schematic for future revisions

Secondary Board Challenges



Oussama Benamar Hlimi
Electrical Engineer

- IR LEDs Removed From the Secondary Board
  - The IR-LED power circuit on the secondary schematic had a design mistake
  - Solution: powered the IR LEDs from the main power-distribution bus instead of the secondary board

- Secondary PCB Randomly Resetting
  - One secondary board would reset on its own every once in a while
  - Root cause: the MCU on that board was not soldered properly (cold solder joint)
  - Solution: re-soldered / reflowed the MCU, which stopped the random resets

Lessons Learned & Future Improvements

- **What We Would Do Differently**
  - Verify every power/ground net and connector footprint against the datasheet before ordering PCBs
  - Place bypass and bulk capacitors right at the regulator pins in layout
  - Add test points and 0-ohm jumpers on critical nets to make rework and debugging much easier

- **Future Improvements**
  - Implement the wired Pi <-< MCU link correctly so the system does not have to fall back to wireless
  - Add reverse-polarity and overcurrent protection to avoid frying MCUs during bring-up

Software Challenges

Kimberly Lugo
Computer Engineer

Difficulties

- Maintaining reliable live streams from both camera nodes
- Stabilizing detections in difficult under-vehicle scenes
- Coordinating Pi 5 decisions with ESP32 commands and acknowledgments

Solutions

- Added automatic stream reconnection and frozen-frame checks
- Applied the 2-out-of-3 frame decision rule
- Used acknowledged START, HAZARD, and CLEAR commands

Budget

Kimberly Lugo
Computer Engineer

Category	Cost
Electrical engineering hardware	$312.20
Optical engineering hardware	$885.97
Computer engineering hardware	$304.68
Grand total	$1,502.85

Work Distribution

Kimberly Lugo
Computer Engineer

Electrical Engineering	Role
Oussama Benamar Hlimi	Power system design and implementation (Primary)
	Motor and actuation system development (Primary)
	Voltage regulation and power distribution (Primary)
	Mechanical integration and mounting (Primary)
	Integration support (Secondary)

Electrical Engineering	**Role**
Christopher Nunez-Velasquez	Deterrent System design and implementation (Primary)
	Circuit Design and prototyping (Primary)
	Speaker, strobe light, and stopping mechanism development (Primary)
	Hardware troubleshooting and testing (Primary)
	Integration support (Secondary)

Work Distribution

Kimberly Lugo
Computer Engineer

Optics and Photonics Engineering	Role
Theresa Dinh	Optical system design and specification (Primary)
	Lens modeling and simulation (Primary)
	Optical testing and calibration (Primary)
	Camera alignment integration (Primary)
	Software integration support (camera interface) (Secondary- with Kim)

Computer Engineering	Role
Kimberly Lugo	Software architecture design (Primary)
	Raspberry Pi setup and configuration (Primary)
	Image processing and YOLOv11 implementation (Primary)
	Dataset creation and AI training (Primary)
	Integration support (Secondary)

References

[1] Knight, H. (2025, December 5). How Kit Kat Was Killed: Video Shows What a Waymo Couldn’t See. The New York Times. https://www.nytimes.com/2025/12/05/us/waymo-kit-kat-san-francisco.html

[2] 1 Plastic + MetalBaby Car Bdm0936G Small Off-Road 12V4.5Ah LongweiMotor 390#*2Drive 12V500Ma Positive Energy. (2026). Walmart.com. https://www.walmart.com/ip/1-Plastic-MetalBaby-Car-Bdm0936G-Small-Off-Road-12V4-5Ah-LongweiMotor-390-2Drive-12V500Ma-Positive-Energy/11741857192