Parking Garage Management System

Group 11:

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MEET THE TEAM

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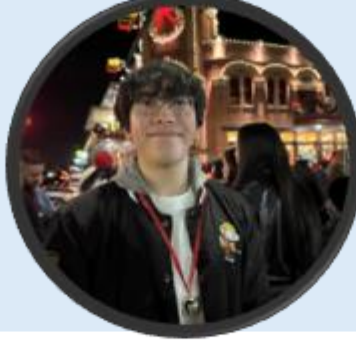
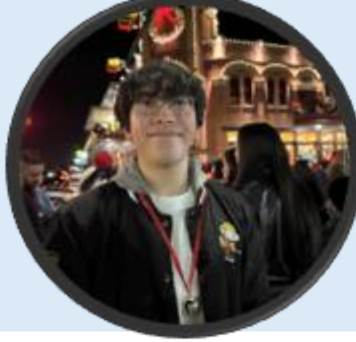
Motivation

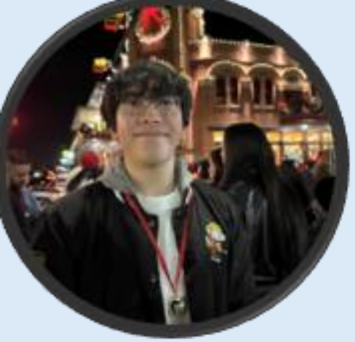


- Busy parking garages are a pain to deal with
  - Finding parking spots during peak times are hard
  - Difficult to tell if parking garages are busy
- Dealing with permits and gates could be confusing
- For smart parking garages, systems can go down from natural disasters

Goal & Objectives



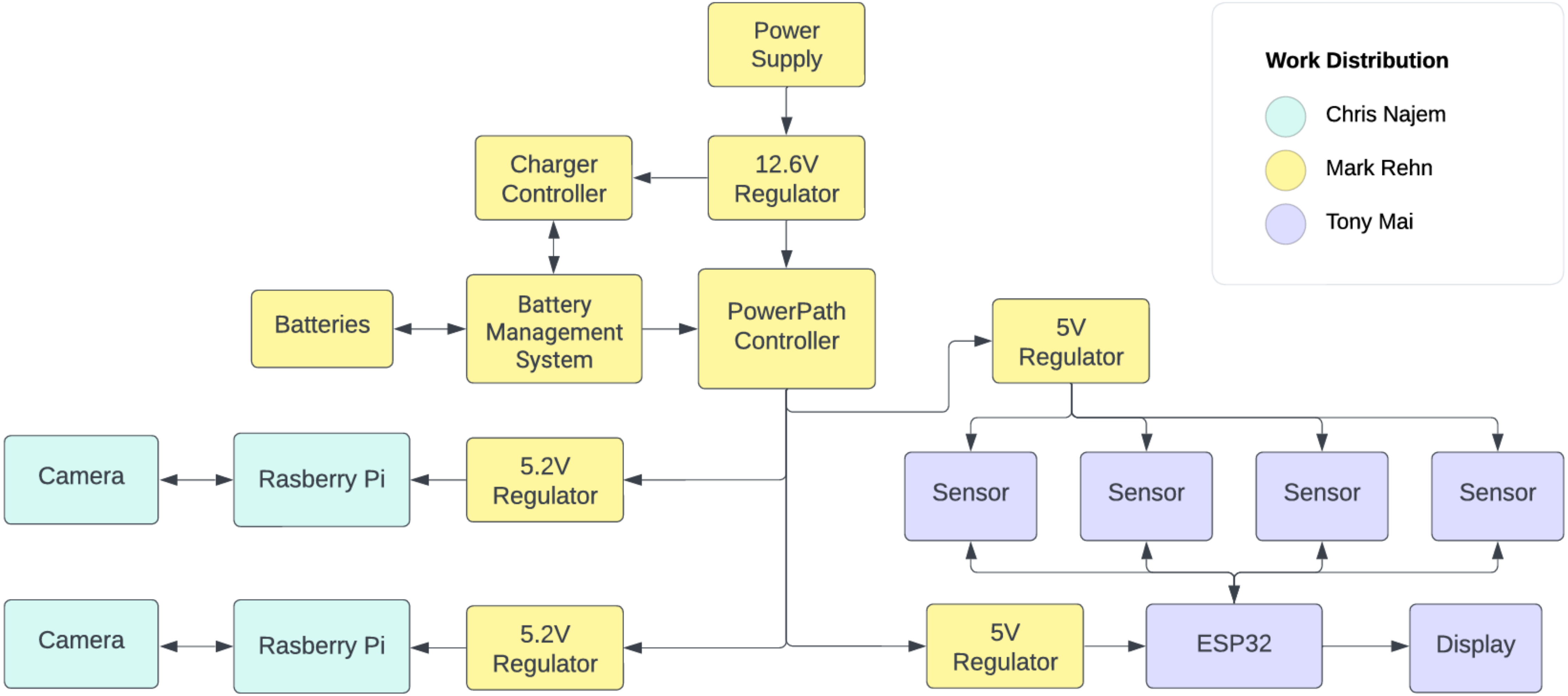
- LED indication for parking spots
- Displays to show free parking spots
- Website that shows free parking spaces and permit information
- Cameras to help with license plate detection for permits
- Battery backup system in case power runs out



Engineering Specifications

Specification	Value/Range	Description
Ultrasonic Sensor Accuracy	≥95%	Accuracy of ultrasonic sensors in detecting parking spot occupancy.
License Plate Recognition	≥85%(daytime) ≥80% (nighttime)	Accuracy of LPR cameras in identifying license plates under varying lighting conditions.
System Uptime	≥99.9%	The system's operational availability over a given time period.
Real-Time Updates	<5 second	Time for parking availability updates to propagate through the system.
Battery Life	≥12 hours	Minimum operational time using battery system in case of power failure.
Payment Processing Time	<10 seconds	Time required for completing parking permit transactions.
LED Indicator Visibility	≥20 meters	Distance from which LED indicators for parking spots can be clearly seen.
Power Efficiency	≥85%	Efficiency of the battery management system in converting and using stored energy.
Backend Server Processing Speed	<500 ms	Maximum time for the backend server to process sensor and camera data.
Dashboard Alert Time	<2 seconds	Time for the admin dashboard to reflect alerts from the system.

Hardware Block Diagram



Power Supply Selection

Technologies Considered:

- Linear Power Supply
- **Switching Power Supply**
- Battery-Based Power Supply

Part Selection:

- ALITOVE 12V 5A power supply
  - Built-in protections: OVP, OCP, SCP
  - Efficient, reliable, and cost-effective

Feature	ALITOVE 12V 5A	Mean Well LRS-60-12	T-Power 12V 5A
Input Voltage	100-240V AC	100-240V AC	100-240V AC
Output Voltage	12V DC	12V DC	12V DC
Max Output Current	5A	5A	5A
Efficiency	85-90%	90%	80%
Protections	Over-voltage, over-current, short-circuit	Over-voltage, over-current, short-circuit	Over-voltage, over-current
Reliability	High	High	Moderate
Price	$11.99	$49.99	$9.99

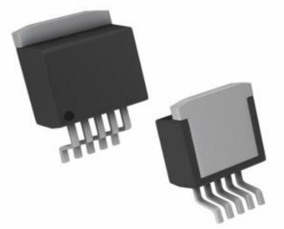
Voltage Regulator Selection

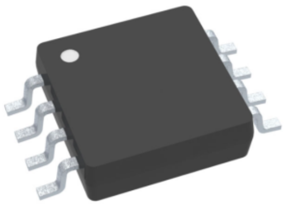
Technologies Considered:

- Linear Voltage Regulators
- **Switching Voltage Regulators**

Part Selection:

- LM2596 buck converter
- LM3478 boost converter





Feature	LM2596 Buck Converter	MP1584EN Buck Converter	LM2575 Buck Converter
Input Voltage	4.5V - 40V	4.5V - 28V	4.75V - 40V
Output Voltage	1.2V - 37V	0.8V - 25V	1.23 - 37V
Output Current	3A	3A	1A
Brand	Texas Instruments	Monolithic Power Systems	Texas Instruments
Price	$3.53	$4.02	$3.58

Feature	LM3478 Boost Converter	TPS61288 Boost Converter	LM3488 Boost Converter
Input Voltage	2.9V - 40V	2V - 18V	2.9V - 40V
Output Voltage	Up to 60V	4.5 - 18V	4.5V – 12.6V
Output Current	Adjustable with an external resistor	15A	Adjustable with an external resistor
Brand	Texas Instruments	Texas Instruments	Texas Instruments
Price	$2.34	$5.33	$2.29

PowerPath Controller Selection

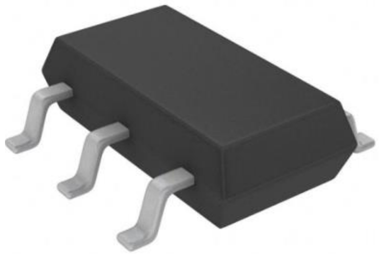
Technologies Considered:

- Diode
- MOSFET
- **Dedicated PowerPath**

Part Selection:

- LTC4412 PowerPath

Feature	LTC4412 PowerPath
Input Voltage	2.5V - 28V
Output Voltage	Vin ± 0.3V
Output Current	Wide Range of Current
Brand	Analog Devices Inc.
Price	$5.91



Charger Controller Selection

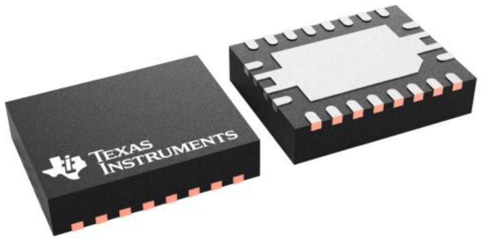
Technologies Considered:

- **Pulse Width Modulation (PWM)**
- Maximum Power Point Tracking (MPPT)

Part Selection:

- BQ24130 Charger Controller
  - RC-settable
  - Supports multi-cell packs

Feature	BQ24130	LT1511	BQ24650
Input Voltage Range	4.5V – 17V	11V – 28V	5V – 28V
Output Voltage	4.2V – 13.5V	1V – 20V	2.1V – 26V
Max Charge Current	2.5A	4A	10A
Efficiency	High	High	High
Protections	Overvoltage, Overcurrent, Thermal	Overvoltage, Overcurrent, Thermal	Overvoltage, Overcurrent, Thermal
Number of series cells	Up to 3	Up to 4	Up to 6
Control interface	Standalone (RC-Settable)	Programmable	Standalone (RC-Settable)
Price	$1.98	$8.12	$1.85



Batteries Selection

Technologies Considered:

- **Lithium-ion**
- Lithium Iron Phosphate
- Nickel Metal Hydride

Part Selection:

- Panasonic NCR18650B
    - Suitable for 3S configuration
    - Widely used

Feature	INR18650-25R	NCR18650B	MJ1
Nominal Voltage	3.7V	3.6V	3.6V
Capacity	2500mAh	3400mAh	3500mAh
Max Continuous Discharge Current	20A	6.75A	10A
Energy Density	~200 Wh/kg	~240 Wh/kg	~240 Wh/kg
Cycle Life	~250-300 cycles	~250-500 cycles	~300-500 cycles
Weight	~43g	~47.5g	~49g
Price	$3.99	$7.99	$5.99

Battery Management System Selection

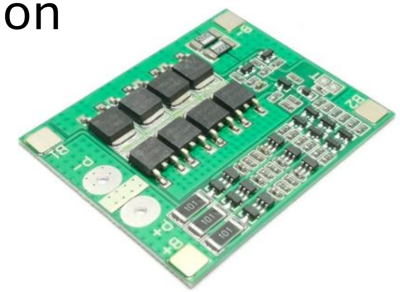
Technologies Considered:

- **Centralized BMS**
- Distributed BMS
- Modular BMS

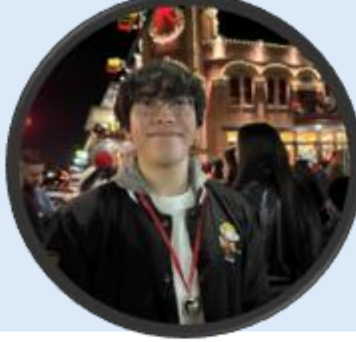
Part Selection:

- HX-3S-FL25A-A BMS
  - Designed for 3S Li-ion battery pack
  - Easy integration, no configuration required

Feature	HX-3S-FL25A-A BMS
Number of Cells	3S
Nominal Battery Voltage	11.1V
Max Charging Voltage	12.6V
Max Continuous Discharge Current	25A
Overcharge voltage range	4.25-4.35V per cell
Overdischarge voltage range	2.3-3.0V per cell
Protection Features	Overcharge, Overdischarge, Overcurrent, Short Circuit
Cost	Low



MCU Selection



Technologies Considered:

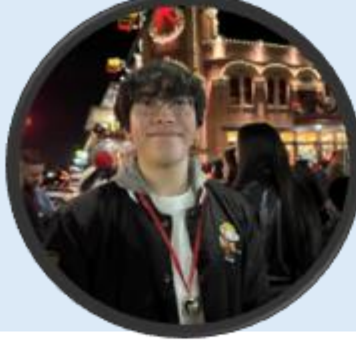
- **ESP32**
- ESP8266
- RP2040

Part Selection:

- ESP32-S3
  - More GPIO pins
  - Wi-Fi and Bluetooth
  - Efficient

Models	Cores	Clock Speed	Wi-Fi	Bluetooth	SRAM	Average Active Power Consumption (mW)	Physical GPIO Pins
ESP32	Single/Dual-core Xtensa LX6	Up to 240 MHz	YES	YES	520 KB	78.32 mW	34
ESP32-S3	Dual-core Xtensa LX7	Up to 240 MHz	YES	YES	512 KB	78.32 mW	45
ESP32-S2	Single-core Xtensa LX7	Up to 240 MHz	YES	NO	320 KB	78.32 mW	43
ESP32-H2	Single-core 32-bit RISC-V	Up to 96 MHz	NO	YES	320 KB	78.32 mW	28

Parking Sensor Selection



Technologies Considered:

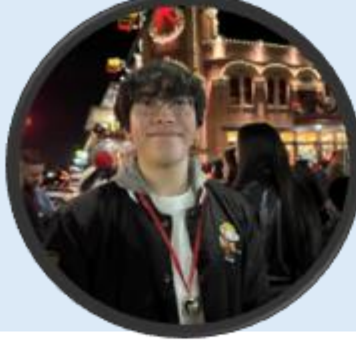
- **Ultrasonic Sensor**
- Geomagnetic Sensor

Part Selection:

- HC-SR04 Ultrasonic Sensor
  - Cheaper
  - Accurate
  - Prior User Experience

Features	SparkFun HC-SR04	MaxBotix MB7360	MaxBotix MB1014
Operating Voltage	5V	2.7V - 5.5V	2.5V - 5.5V
Range	2cm - 4m	30cm - 5m	15cm - 6.4m
Response Time	~50ms	~100ms	~100ms
Accuracy	±3mm	±1mm	±2.5cm
Current Draw	15mA	2.3mA - 3.1mA	2mA - 3mA
Beam Angle	15 degrees	11 degrees	44 degrees
Size	Length: 45mm Width: 20mm Height: 13.5mm	Diameter: 43.8mm Length: 65.1mm	Length: 22.1mm Width: 19.9mm Height:15.5mm
Cost	~$4	~$110	~$30

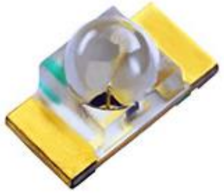
LED Selection



Technologies Considered:

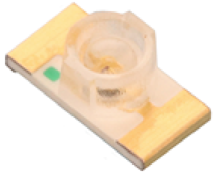
- **SMD LEDs**
- DIP LEDs
- COB LEDs

Features	APTBD3216SURKCGKC-01	VFR1105W-6C9-TR	APTL3216ZGCK-01
Operating Voltage	Green: 2.1V Red: 1.95 V	1.9 V	3.3 V
Brightness	Green: 250 mcd Red: 600 mcd	985 mcd	1000 mcd
Colors	Green and Red	Red	Green
SMD Package Size	1206	1206	1206
Cost	$0.58	$0.36	$0.58

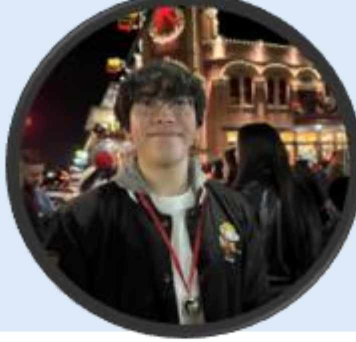


Part Selection:

- VFR1105W-6C9-TR LED (Red)
- APTL3216ZGCK-01 LED (Green)



Display Selection



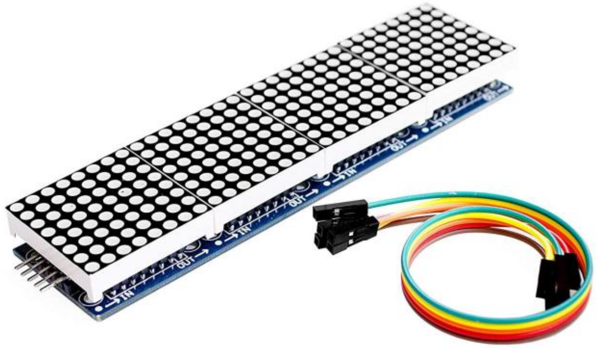
Technologies Considered:

- **LED Display**
- LCD Display

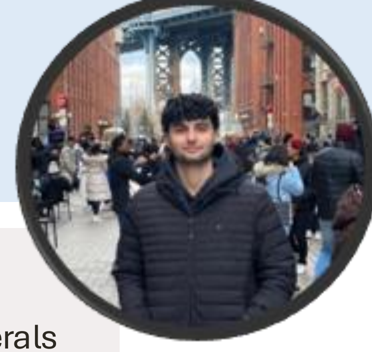
Features	TM1637	MAX7219	P10 LED Display
Operating Voltage	3.3V - 5V	4V - 5.5V	5V
Size (mm)	66 mm x 27.5 mm	128 mm - 32 mm	320 mm x 160 mm
Power Draw	~80 mA	~67 mA	~2 A
Brightness	Mediocre	Mediocre	Good
Numbers/Text	Numbers	Both	Both
Cost	~$3 - $7	~$3 - $9	~$20 - $50

Part Selection:

- MAX7219 Dot Matrix Display
  - Low Cost
  - Low Power Consumption
  - Easier Usage



LPR Microprocessor Selection Overview



Crucial Role

Microprocessors are vital for real-time image recognition and data handling in embedded systems.

Key Considerations

Computational power, energy efficiency, software compatibility, and cost are critical factors.

System Integration

Seamless integration with peripherals and necessary software libraries is essential for LPR.

Parameters	Raspberry Pi 4	NVIDIA Jetson Nano	Google Coral Dev Board	BeagleBone AI-64
Cost	$65	$230	$150	$190
Power consumption	3-5W	5 W and 10 W (default)	3.2W	5W
Supply Voltage	5.1V	5v	5v	5v
Memory	2GB/4GB/8GB LPDDR4	4GB LPDDR4	1GB/4GB LPDDR4	4GB LPDDR4
Storage	MicroSD	MicroSD	8/16 GB eMMC, MicroSD slot	16 GB eMMC, MicroSD slot
Built-in WiFi/Bluetooth	Yes	Yes	Yes	Yes
Camera support	1x MIPI CSI, USB Cameras	1x MIPI CSI, USB Cameras	1x MIPI CSI, USB Cameras	2x MIPI CSI, USB Cameras
Connectivity	2x USB 3.0, 2x USB 2.0	4x USB 3.0, USB 2.0 Micro-B	2x USB 3.0, USB 2.0 Micro-B	2x USB 3.0, USB 3.0 type-C
Community support	Extensive, large user base	Moderate, smaller than Raspberry Pi	Limited compared to Pi and Jetson	Niche, minimal community support

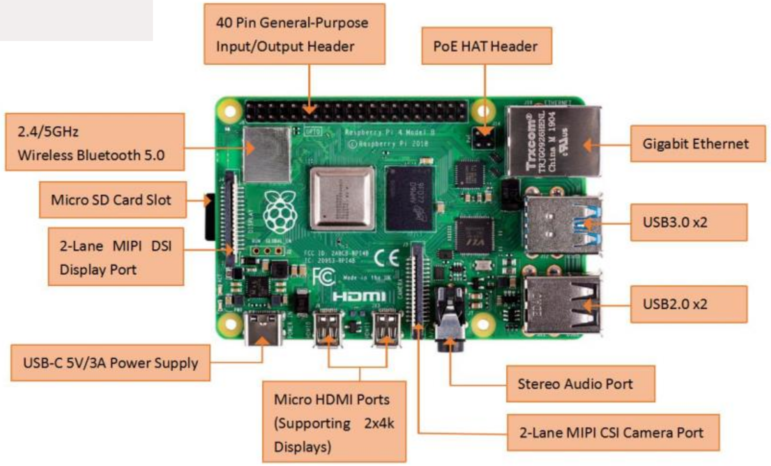
Raspberry Pi 4: The Chosen MPU

Balanced Performance

Offers a strong balance of processing power, affordability, and ease of integration.

Robust Ecosystem

Extensive documentation and community support, compatible with OpenCV.



Camera Integration

Supports MIPI CSI connector for high-resolution camera modules.

Cost-Effective

More affordable than Jetson Nano, making it practical for the project.

Camera Module Comparison

Parameter	Raspberry Pi Camera Module V2	Arducam IMX477	ELP	OAK-D	Axis P1445-LE
Sensor	8MP Sony IMX219	12.3 MP IMX477	2MP IMX323	12MP RGB + Stereo Depth	2MP CMOS
Resolution	1080p30, 720p60	4056 x 3040 pixels	1080p30	4K/30FPS, 1080P/60FPS	1920x1080
Frame Rate	30/60 FPS	30/60 FPS	30 FPS	30/60 FPS	25/30 FPS
Interface	MIPI CSI-2	MIPI CSI-2	USB 2.0	USB 3.0	Ethernet (PoE)
Cost	$15	$60	$60	$249	High ($500)
AI Processing	No	No	No	Yes	Basic Edge AI
Low-Light Performance	Moderate	Good	Excellent	Excellent	Excellent
Ease of Integration	Easy	Easy	Moderate	Advanced	complex
Weatherproof	NO	NO	NO	IP67	IP67

Raspberry Pi Camera Module V2: Final

Affordability

Cost-effective solution for the LPR system.

Easy Integration

Designed for seamless connection with Raspberry Pi boards.

Low-Light Solution

Additional infrared lighting can enhance nighttime detection.

Viable Option

Strong balance of features for initial design.

Database Selection Overview

MySQL

Relational database, fast reads. Fixed table structure can lead to fragmentation. Good for real-time updates.

MongoDB

NoSQL, document-based. Flexible schema, no fragmentation. Excellent for large-scale writes and real-time processing.

PostgreSQL

Object-relational database. ACID compliant, supports custom data types and JSON. More complex to manage.

Feature	MySQL	MongoDB	PostgreSQL
Data Model	Relational (SQL)	Document-Based (NoSQL)	Relational + JSON Support
Scalability	Moderate	High (Sharding)	High (Partitioning, Replication)
Read Performance	High	Moderate	High
Write Performance	Moderate	High	High
Schema Flexibility	Low	High	Medium
ACID Compliance	Yes	Limited (Transactions in newer versions)	Yes
Indexing & Querying	Standard Indexing, Foreign Keys	Indexing on Documents	Advanced Indexing, Full-Text Search
Best Use Case	Structured Data, Transactional Workloads	High-Speed Data Ingestion, Semi-Structured Data	Large Datasets, Complex Queries, Analytics

Server Selection Overview

Local Server

On-premise machine, low latency, high security. Requires manual maintenance and scaling.

Cloud-Based Server

Third-party providers, scalable, automatic updates. Internet dependent, varying complexity.

Feature	Local Server	MongoDB Atlas	AWS EC2	Google Cloud
Latency	Very Low	Moderate (Dependent on Internet)	Moderate	Moderate
Scalability	Limited	High (Automatic Scaling)	High (Manual Scaling)	High (Auto-Scaling)
Data Security	High (Private Infrastructure)	High (Built-in Encryption & Access Control)	Moderate (Requires Custom Security Configurations)	Moderate (Cloud-Based Security)
Maintenance	High (Manual Hardware Upkeep)	Low (Fully Managed)	Moderate (Cloud Admin Required)	Low (Managed by GCP)
Internet Dependency	No	Yes	Yes	Yes
Cost	High (Initial Investment)	Moderate (Subscription-Based)	High (Pay-As-You-Go)	Moderate (Usage-Based Pricing)
Best Use Case	Secure, Offline Applications	Scalable LPR Systems with Automated Management	Large-Scale Deployments with AI Integration	AI-Powered LPR with TensorFlow Support

Server Selection: MongoDB Atlas

1. **Ease of Use**

   Simple to deploy and manage for small-scale projects.

2. **Affordability**

   Cost-effective subscription plans, including a free tier.

3. **Seamless Integration**

   Optimized for our chosen MongoDB database.

LPR Solution Selection Overview

OpenALPR Commercial

High accuracy, but costly with subscriptions starting at $10/month per camera. Requires IP cameras, increasing overall expense.

Plate Recognizer

Accurate and flexible, with a free trial (2,500 lookups/mo). Paid plans start at $50. Compatible with various cameras.

OpenALPR Open Source

Free, offline ALPR solution using OpenCV and Tesseract. Runs on Raspberry Pi with no subscription or special hardware needed.

Feature	OpenALPR (Commercial)	OpenALPR (Open Source)	Plate Recognizer
Cloud-based option	Yes	no	Yes
On-Premises Option	Yes	yes	Yes
Low light performance	Moderate	Basic	Strong
Focus area	Law enforcement, surveillance	Basic LPR needs	Parking management, tolling, security
Hardware dependency	Requires specialized hardware	Works with any camera	Works with any camera
License / Cost	Paid (min $10/mo/cam)	Free (AGPL licensed)	Paid (from $50/mo)
Offline capability	Limited (cloud-focused)	Full offline capability	Limited (cloud-focused)

Selected LPR Solution: OpenALPR Open Source

Cost-Effectiveness

Free core functionality eliminates recurring costs, aligning with our budget.

Hardware Compatibility

Compiles and runs directly on Raspberry Pi 4B with a CSI camera.

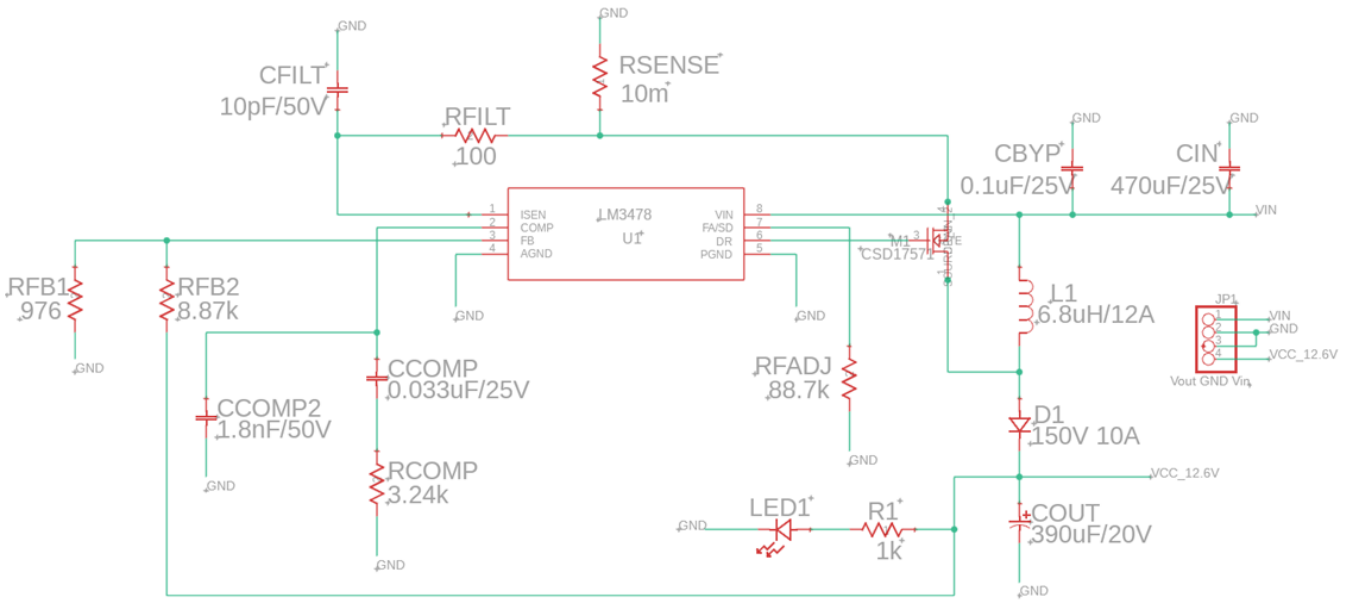
Offline Functionality

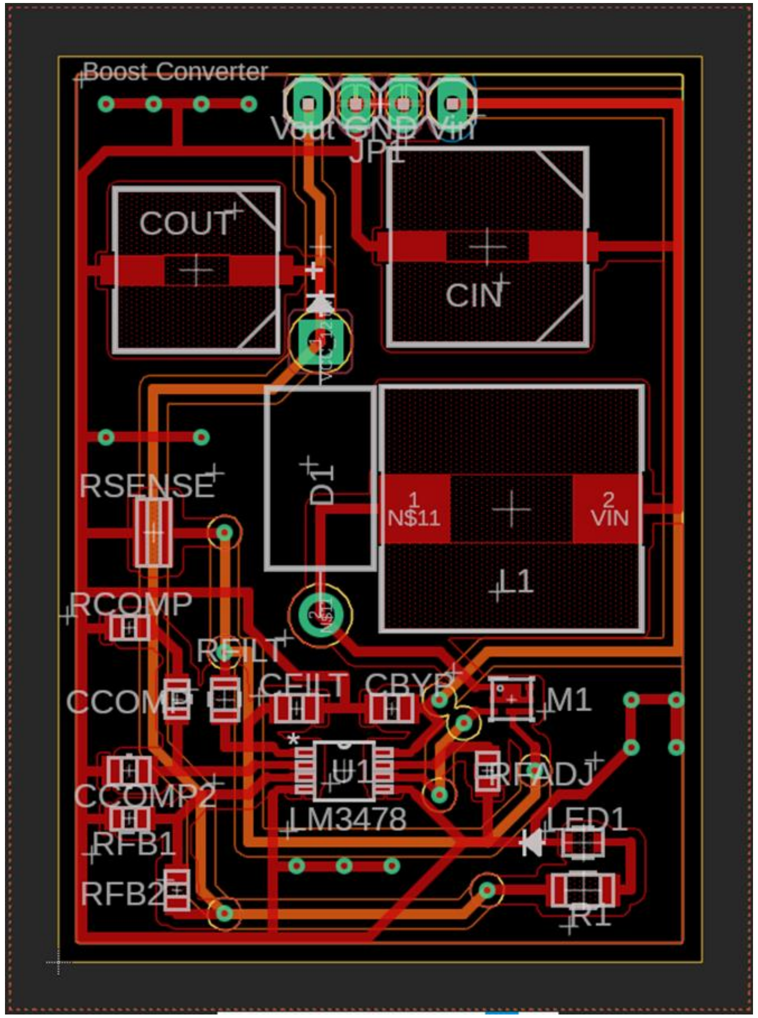
No cloud connectivity needed, enhancing reliability in various environments.

Meets Core Needs

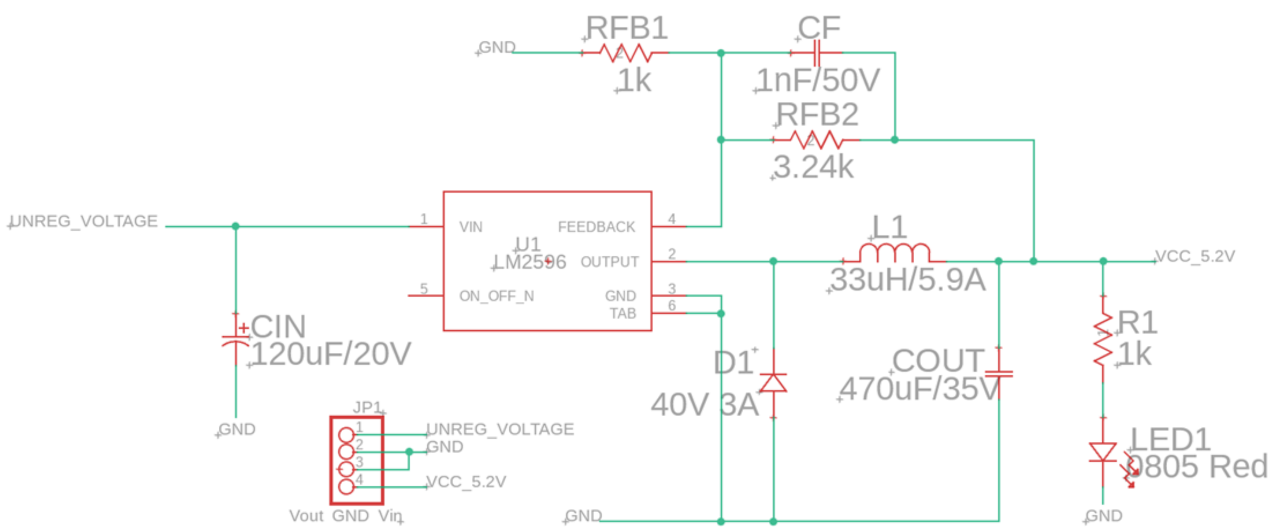
Accurately detects and logs license plate numbers in real-time, fulfilling project requirements.

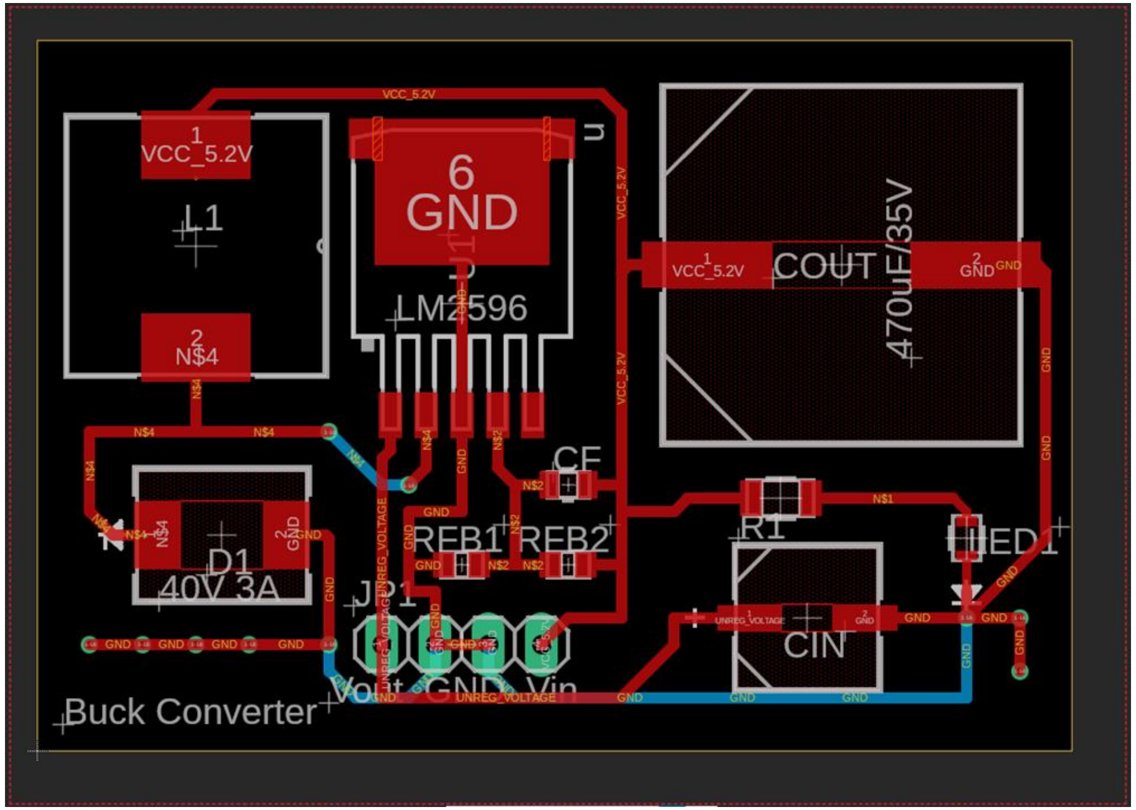
Boost Converter Schematic & Layout



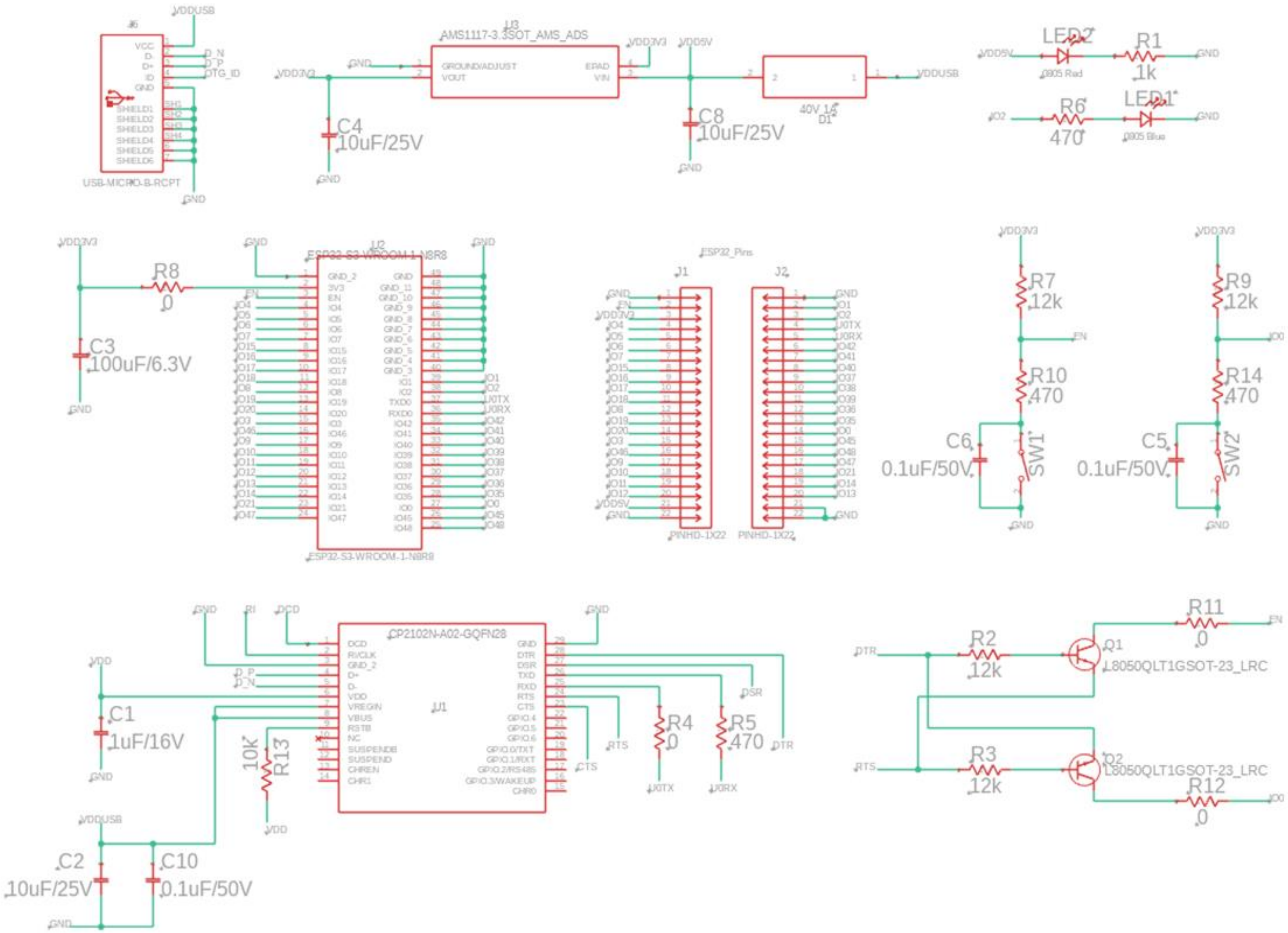


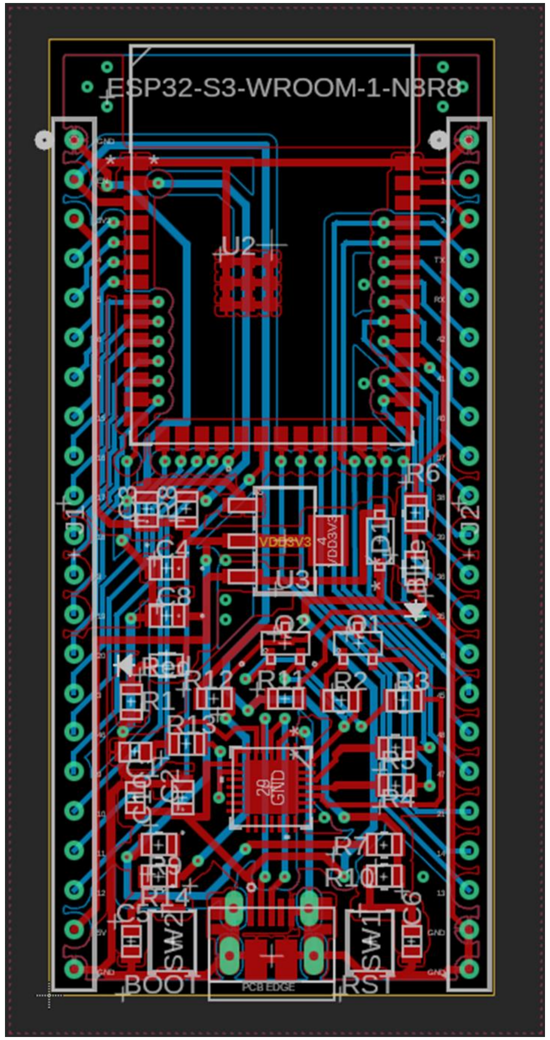
Buck Converter Schematic & Layout



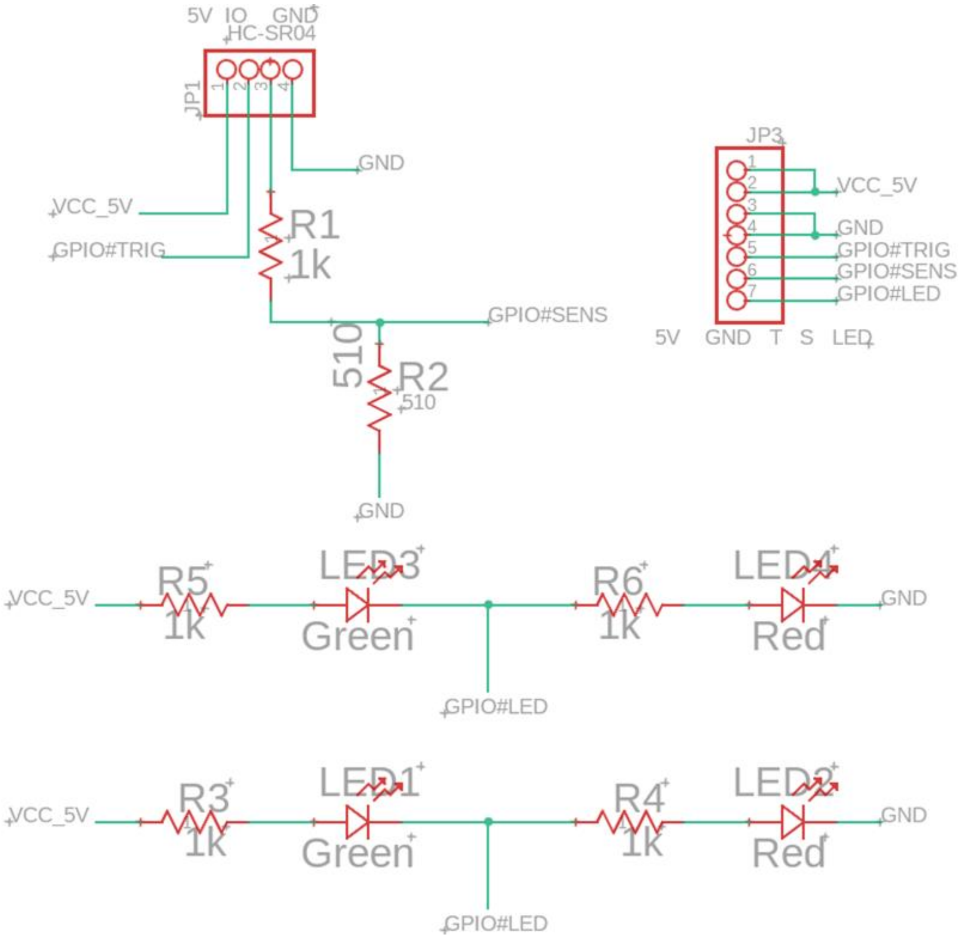


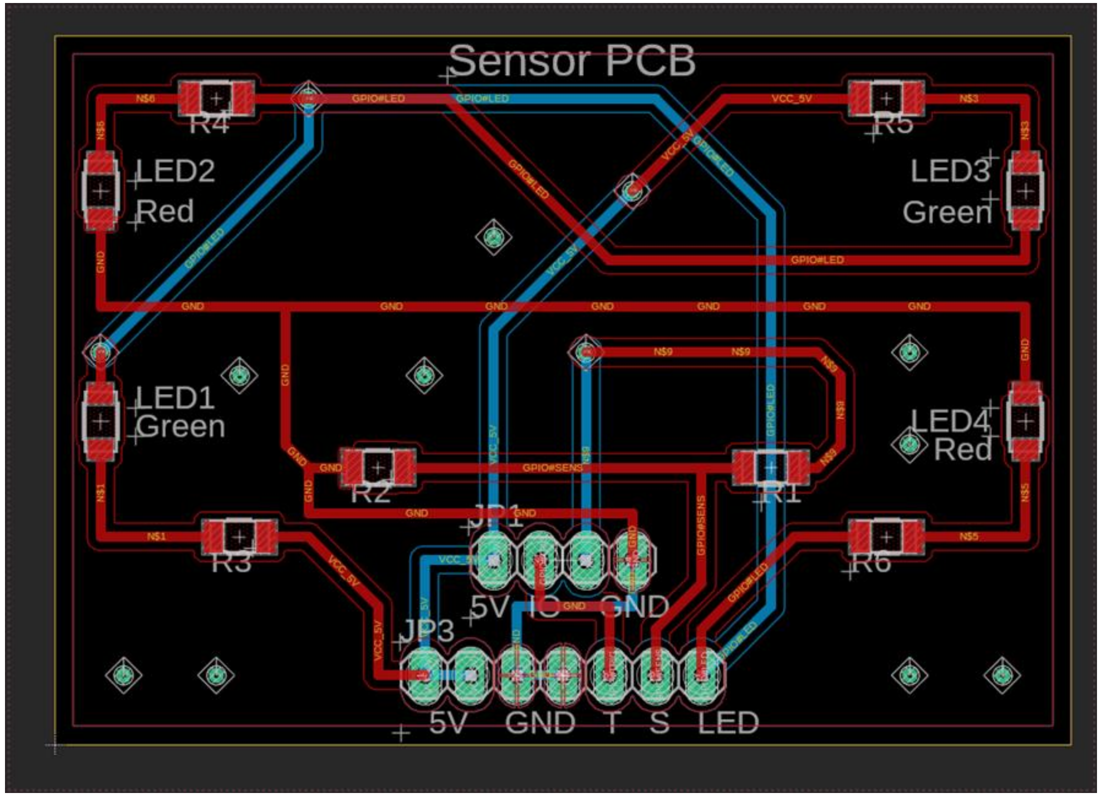
ESP32 Schematic & Layout



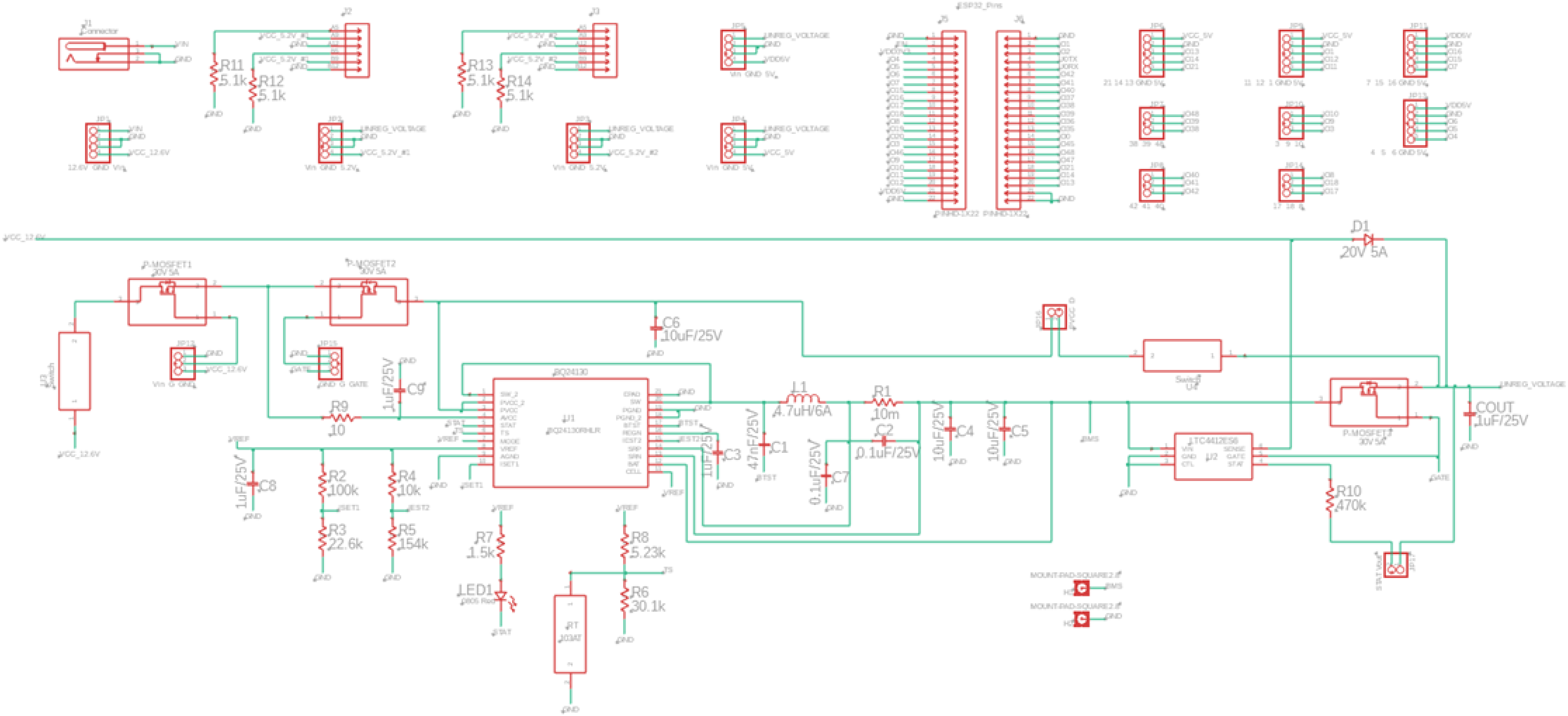


Sensor Schematic & Layout





Main PCB Schematic



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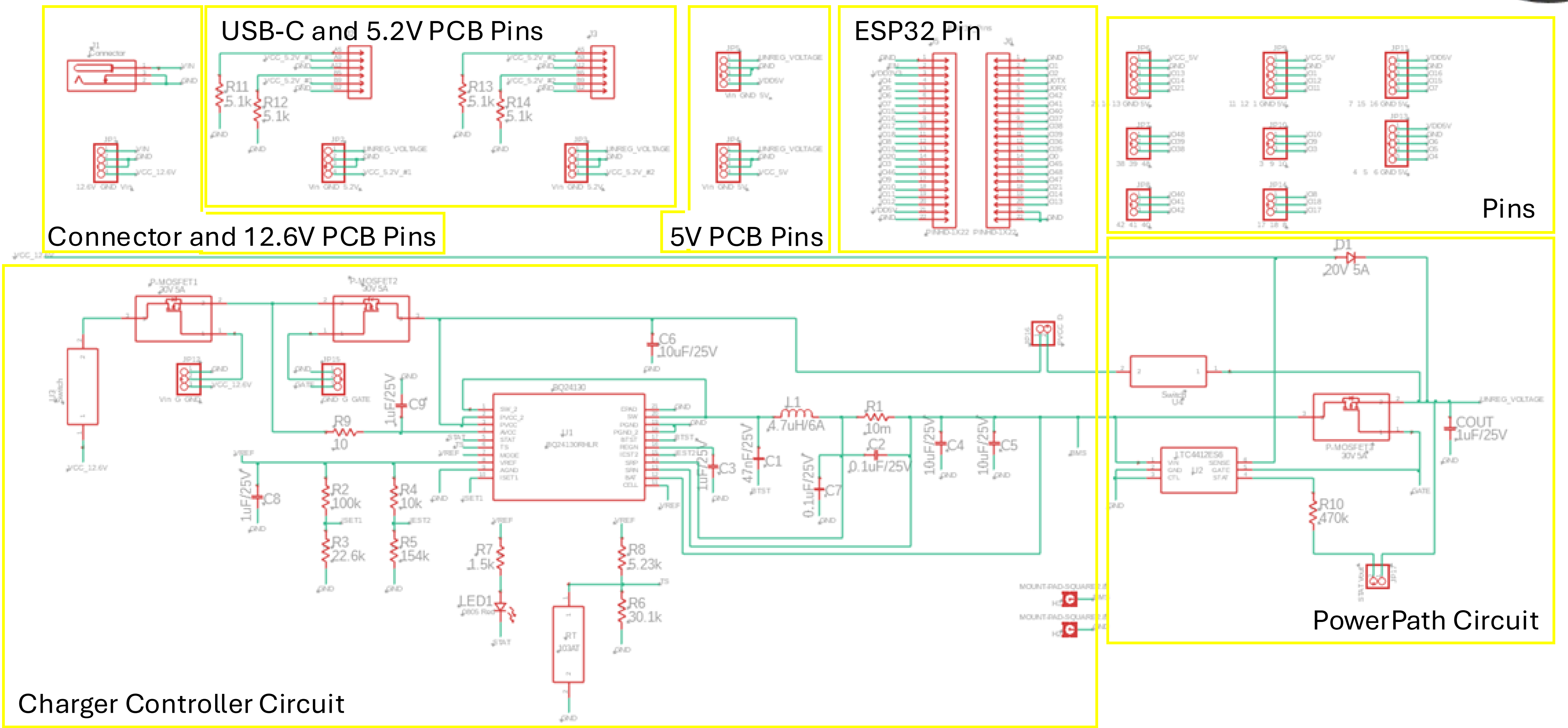
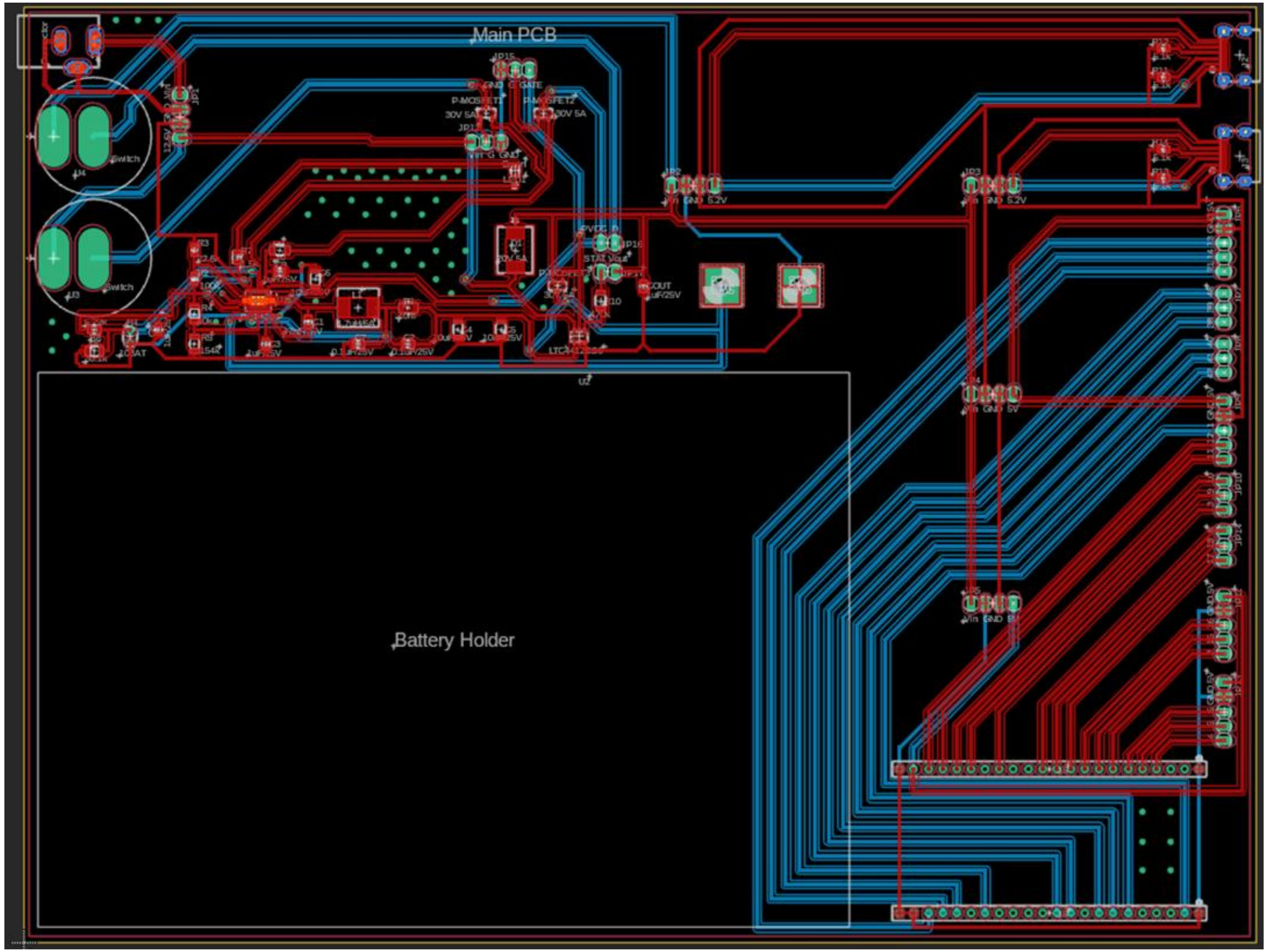


Main PCB Layout



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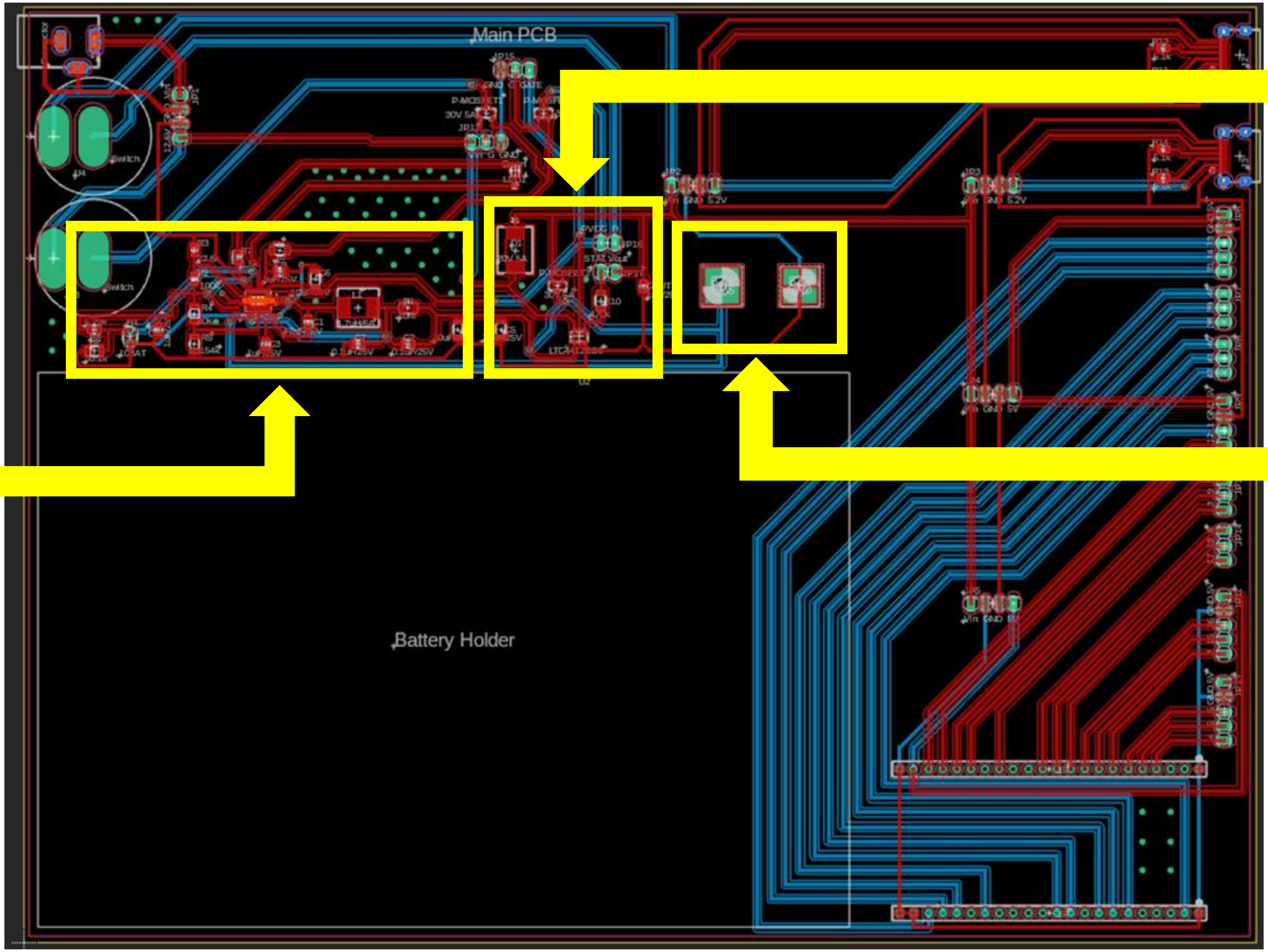
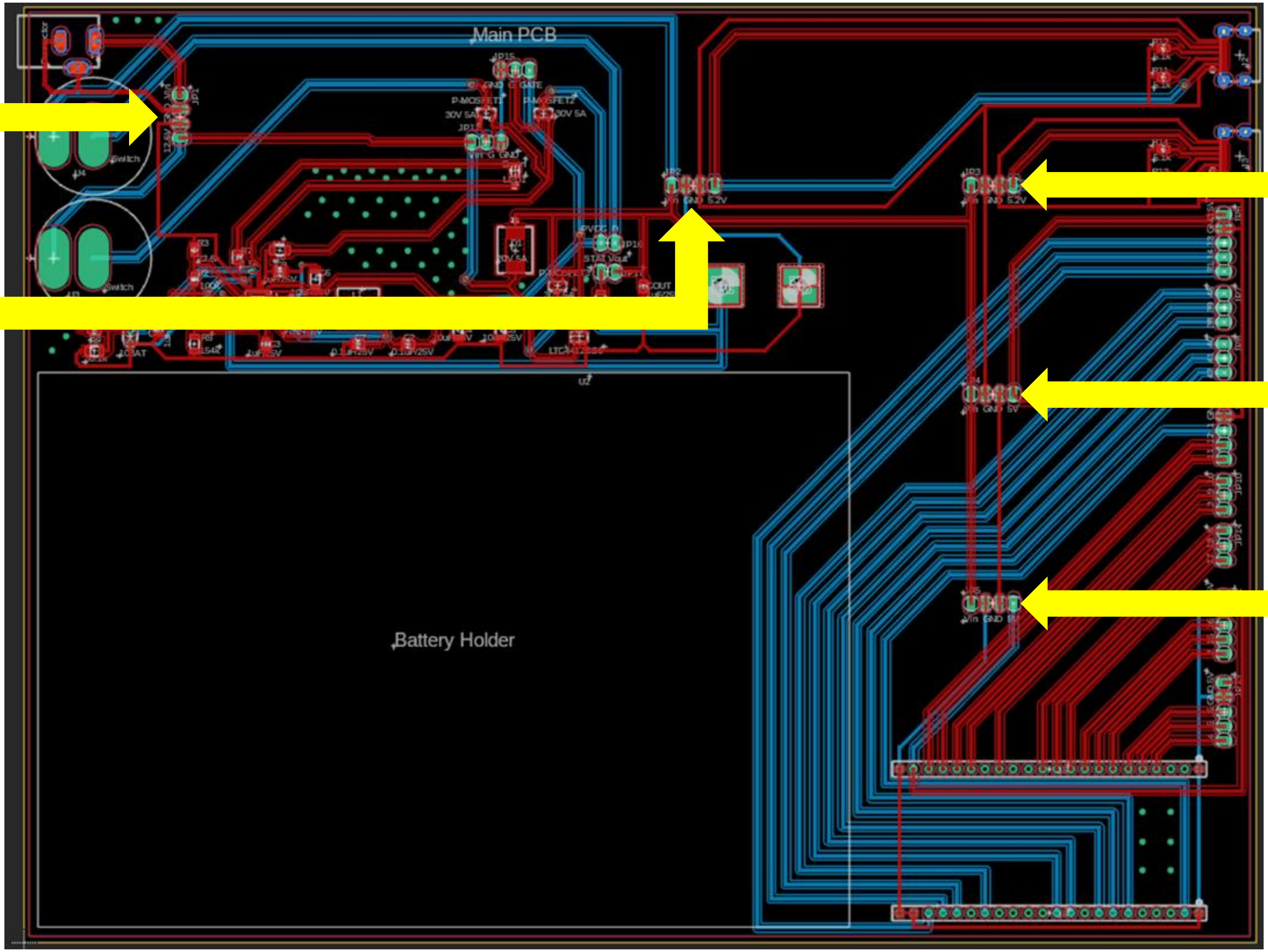


PowerPath Controller

BMS

Charger Controller

Main PCB Layout



12.6V voltage regulator

5.2V voltage regulator

5.2V voltage regulator

5V voltage regulator

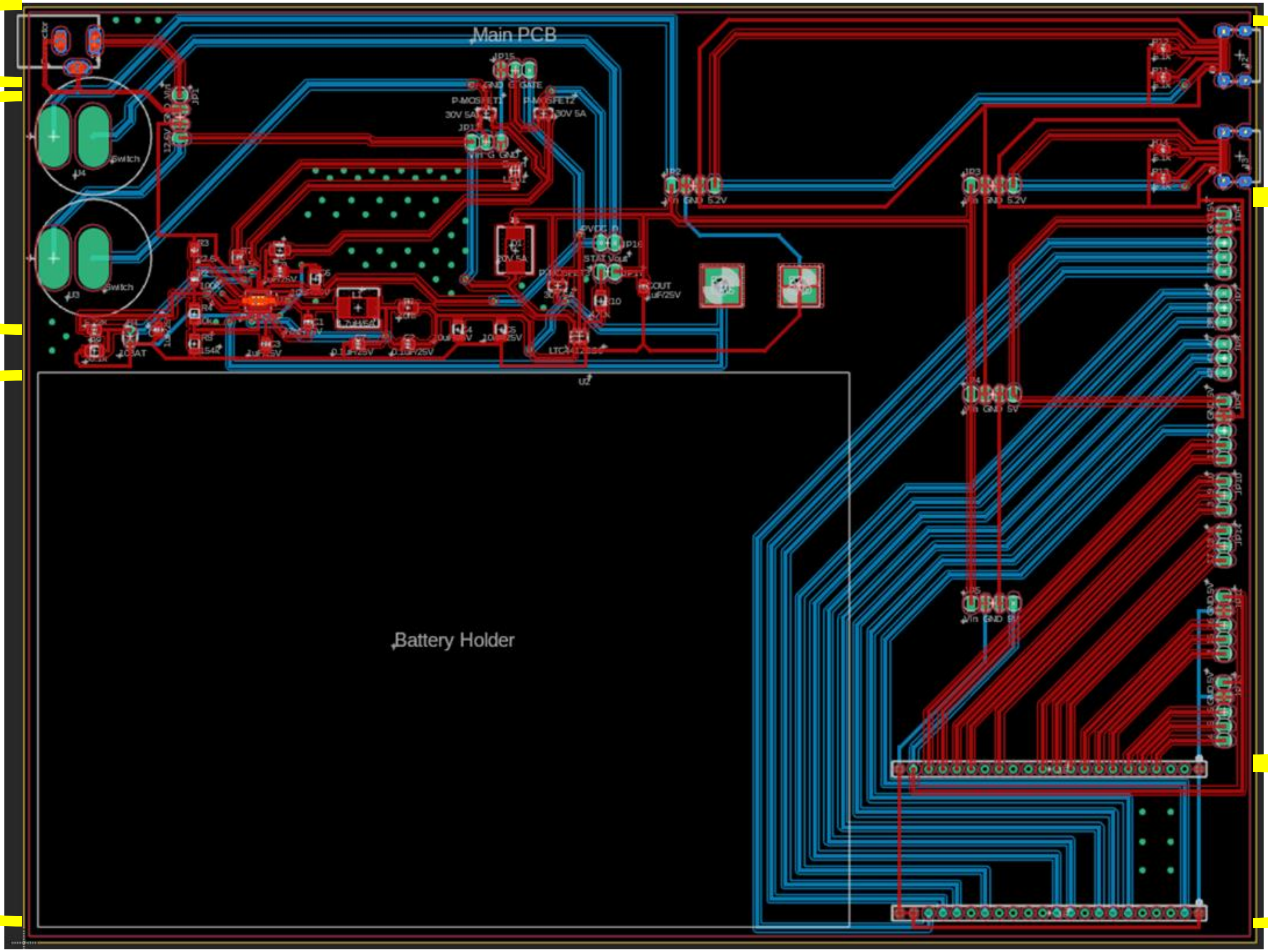
5V voltage regulator

Main PCB Layout

Power supply connector

Switches to turn off the charge controller

Batteries

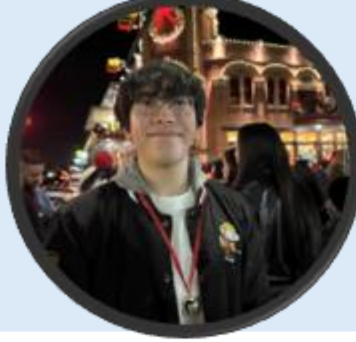


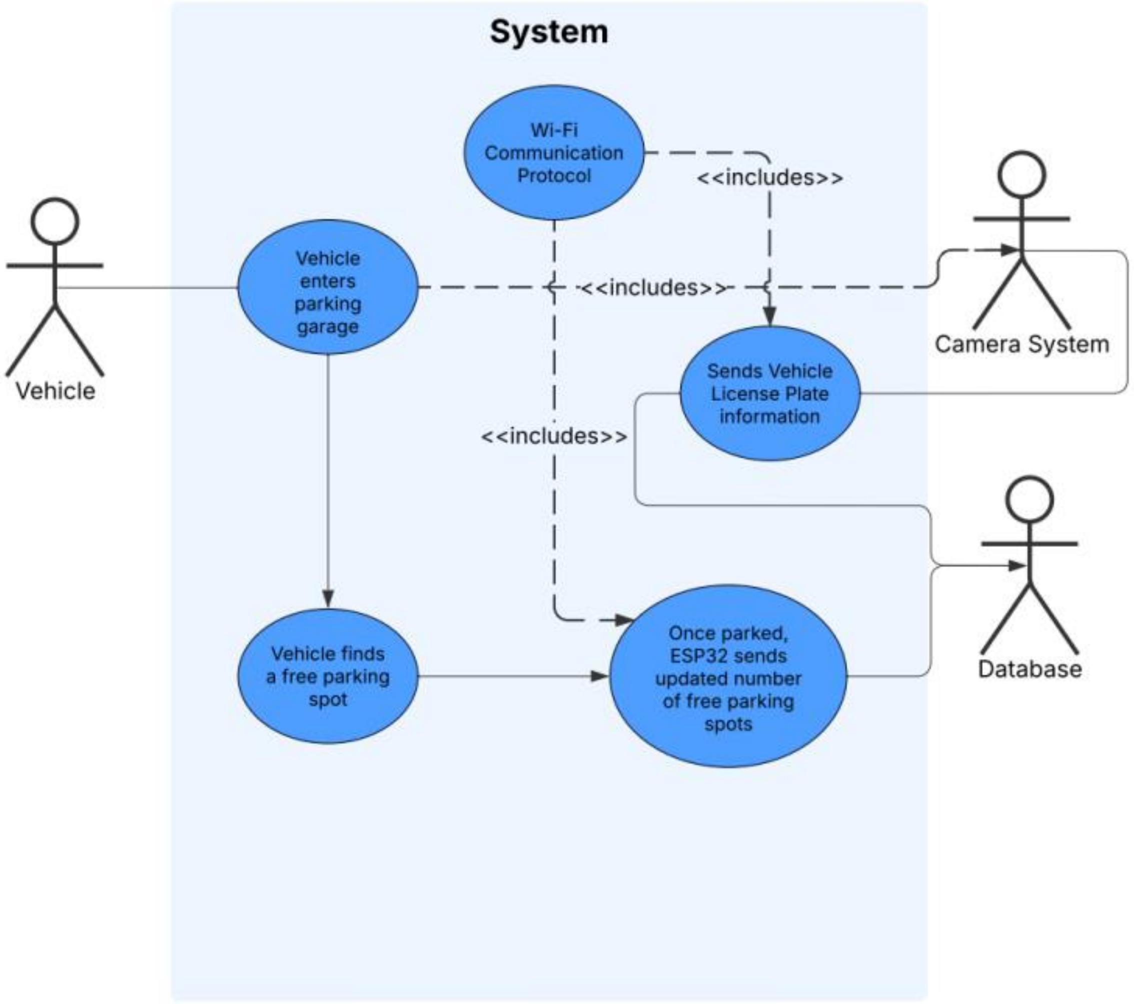
USB-C connectors for Raspberry Pi

Sensor pins

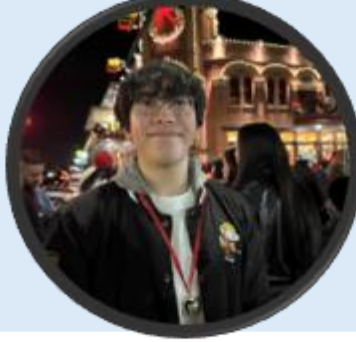
ESP32

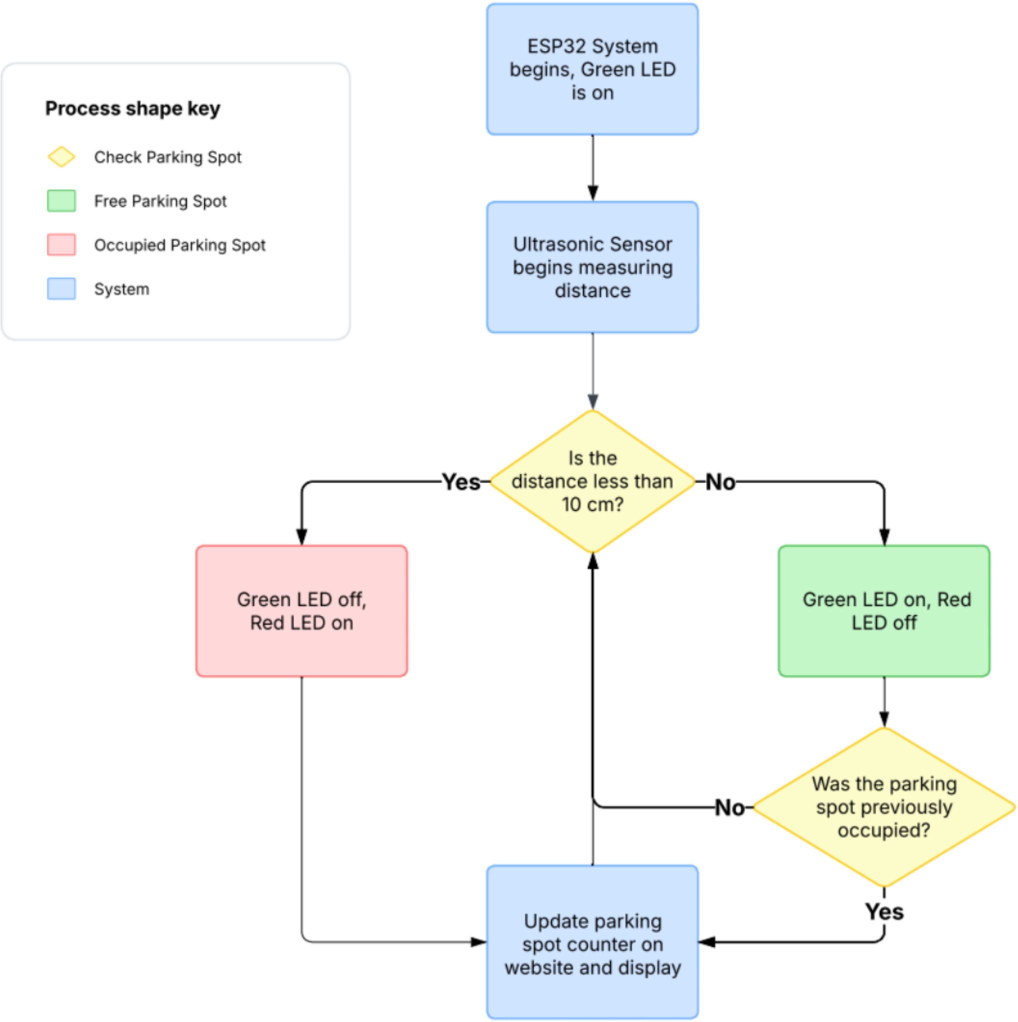
Overall Software Use Case Diagram



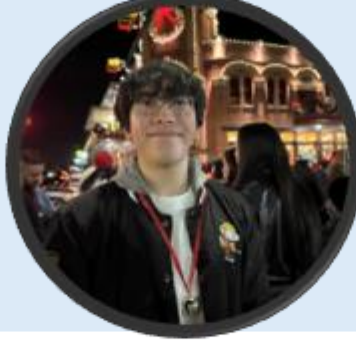


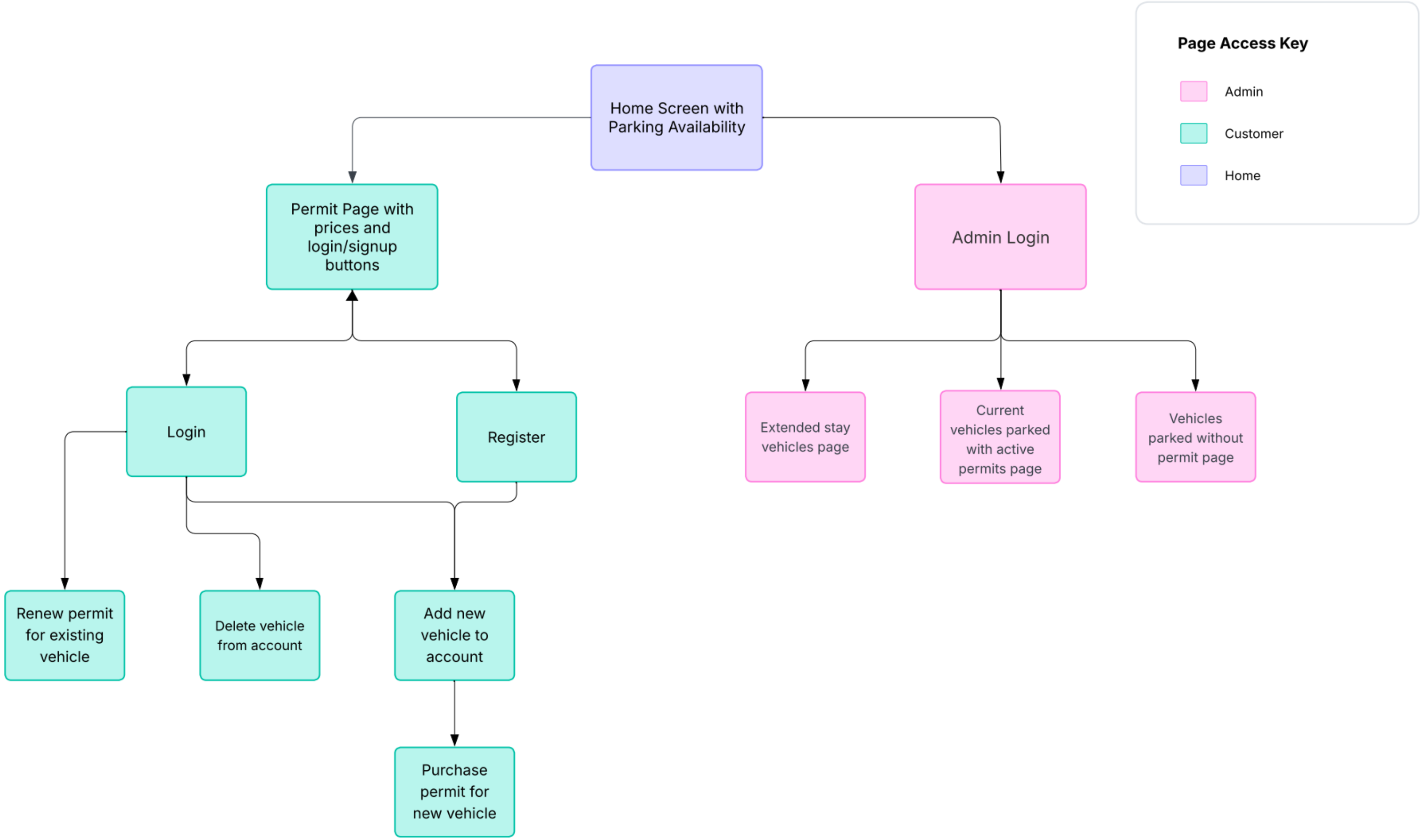
ESP32 System Flowchart



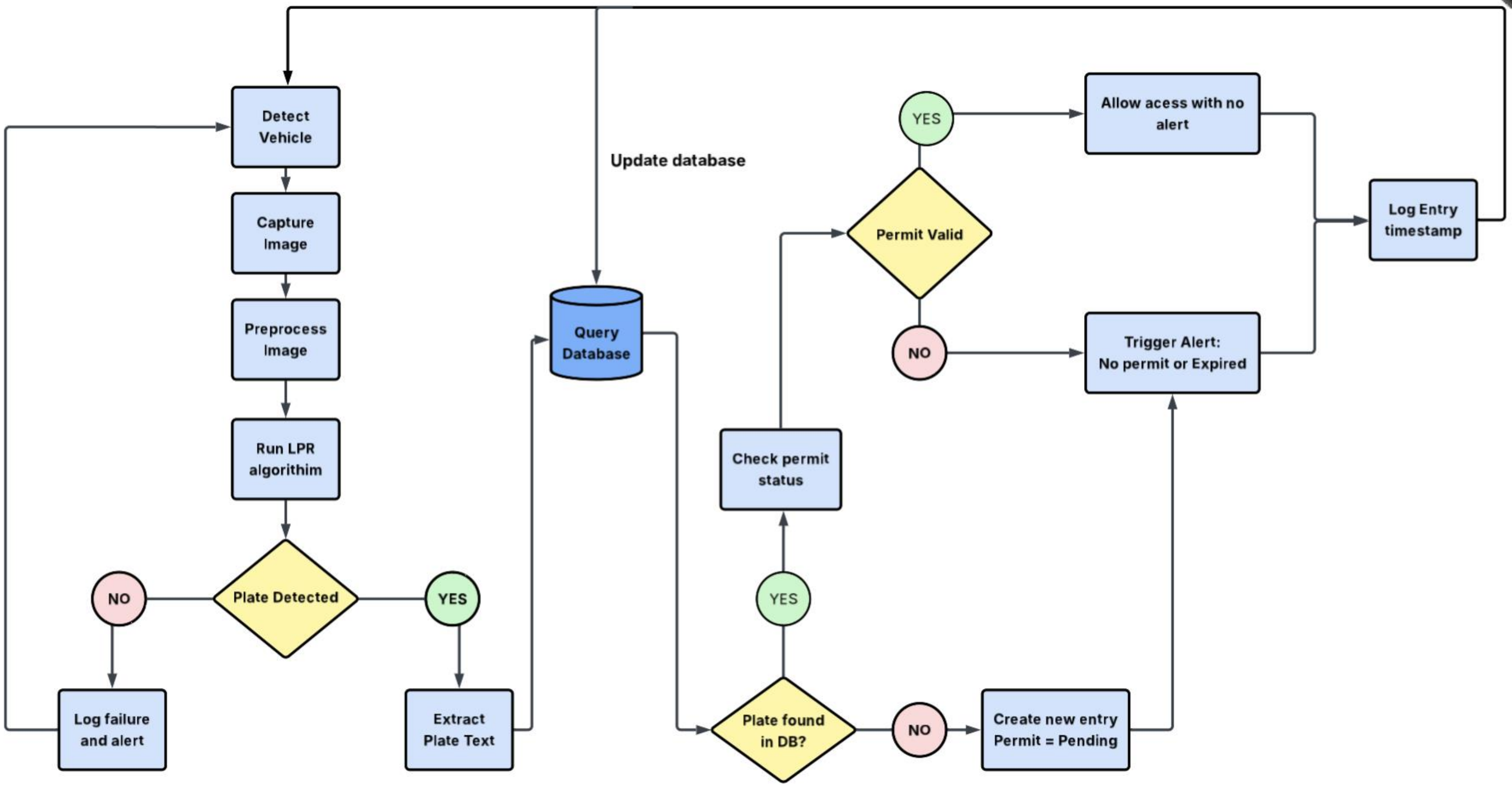


Website Flowchart



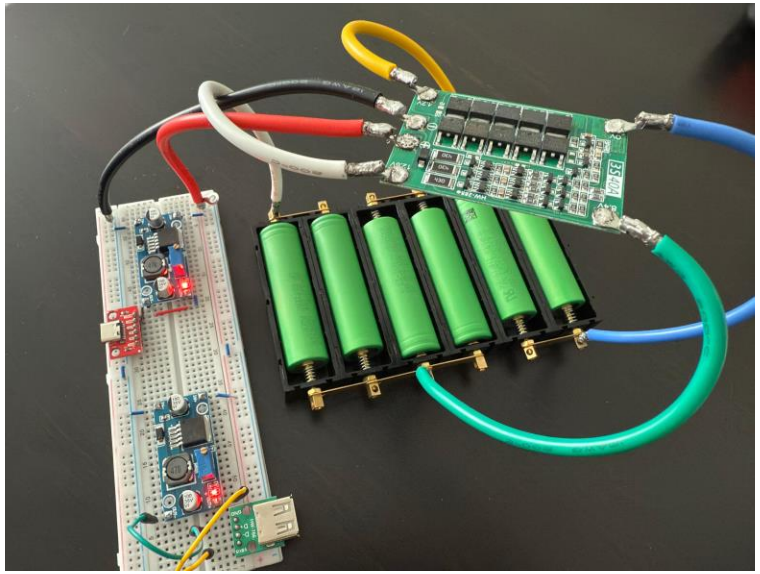


LPR System Flowchart – Logic Description

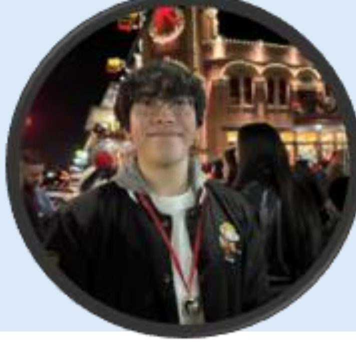


Battery System and Voltage Regulators Testing

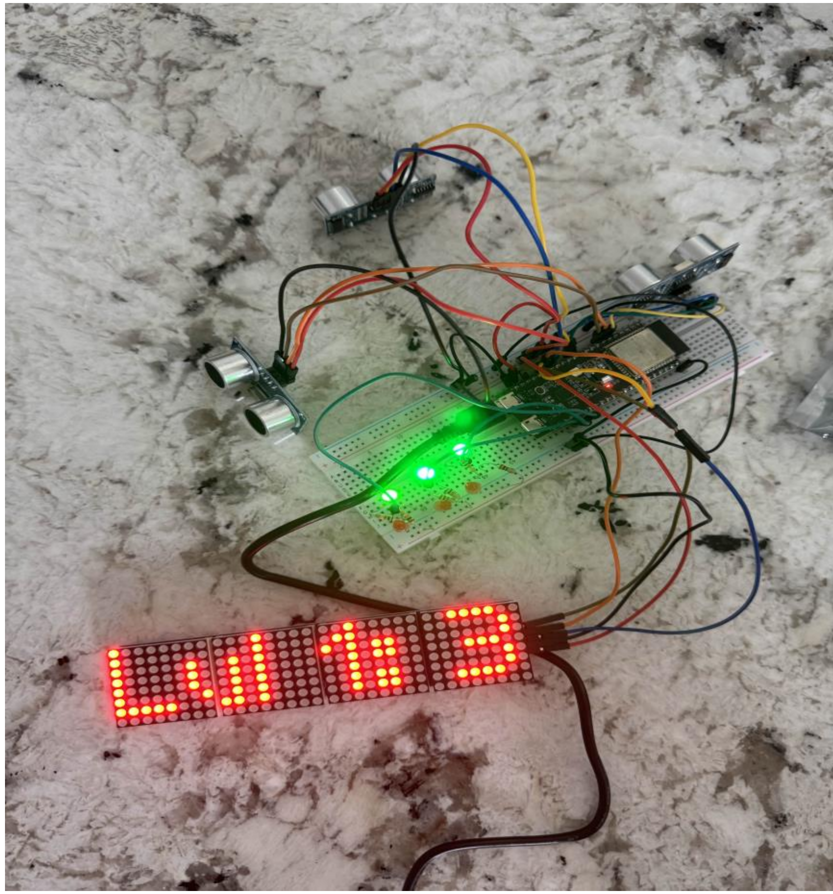
- **Testing:**
  - Battery output voltage when fully charged was around 12.6V
  - Output voltage of one of the regulators was adjusted to be 5.2V for the Raspberry Pi and the other regulator to be 5V for the ESP32
- **Performance:**
  - The battery system and regulators work as expected
- **Problem:**
  - Raspberry Pi showed low power voltage warning
    - Test with the voltage regulator we designed



ESP32 System Testing



- **Testing:**
  - Used Arduino IDE for ESP32 System code
  - Used distance from Ultrasonic Sensor to trigger LEDs
  - MAX7219 LED display uses separate libraries to display text
- **Performance:**
  - Ultrasonic Sensor detection and LED indication works expected
  - MAX7219 Display updates as expected
- **Problem:**
  - P10 LED Display did not work with our version of the ESP32
    - Switched to MAX7219 LED display



LPR Phase 1: Static Image Testing

1 **Terminal Command**

OpenALPR was tested by feeding multiple images via the command line.

2 **Setup**

Raspberry Pi 4B, Debian 12 OS, OpenALPR, and test images were used.

3 **Verification**

The system successfully detected license plate numbers with high confidence.


```
cn20@cn20:~/Pictures $ alpr -c us car1.jpg
plate0: 10 results
    - AM74043    confidence: 92.7465
    - AM74043    confidence: 84.5317
    - AN74043    confidence: 83.7489
    - AM74Q43    confidence: 83.7289
    - AH74043    confidence: 82.5429
    - AM74D43    confidence: 81.2552
    - A74043     confidence: 80.3506
    - AM74B43    confidence: 78.3404
    - AN74043    confidence: 75.5341
    - AN74Q43    confidence: 74.7312
```

Static Test Results:

Successful Detection

The license plate "AM74043" was accurately identified.

High Confidence

The top guess had a 92% confidence rate.

Proved Capability

This phase confirmed OpenALPR's detection ability.

LPR Phase 2: Real-Time Detection

1

Live Feed Testing

We used the Raspberry Pi camera's live feed.

2

Simulated Vehicle

A phone screen displaying a license plate simulated a moving car.

3

Custom Script

A Python script captured images every second for OpenALPR analysis.

Successful Detection

The system detected plates with an 89% confidence score.


```
✅ Plate detected:
No license plates found.

✅ Plate detected:
No license plates found.

✅ Plate detected:
plate0: 10 results
    - DZVG49        confidence: 89.4834
    - DZVCG49       confidence: 82.375
    - DZV649        confidence: 82.3435
    - DZVQ49        confidence: 81.6088
    - DZVO49        confidence: 81.1544
    - DZVG4S        confidence: 80.9121
    - DZVG4B        confidence: 80.7012
    - 0ZVG49        confidence: 80.4803
    - OZVG49        confidence: 80.4638
    - DZVG4         confidence: 80.3441

✅ Plate detected:
No license plates found.

✅ Plate detected:
No license plates found.
```

Next Steps: Challenges & Improvements

Accuracy Decrease

Accuracy dropped when plates where captures from wider angles or further distances.

Proposed Solutions

To reduce error, ensure the plate is centered and use and use an optical zoom lens to maintain clarity from further distances.

Database Integration

Connect LPR to a backend database for plate storage and key data.

Real-World Testing

Test with a real moving vehicle in an outdoor environment.

Hardware Modifications

Improve camera stability with a tripod and add an optical lens.

Estimated Bill of Materials

Component	Subsystem	Quantity	Unit Cost (USD)	Total (USD)
Ultrasonic Sensors	Sensors and Processing	10	$1.91	$19.10
Cameras	Sensors and Processing	2	$14.49	$28.98
LED Indicators	Sensors and Processing	20	$0.15	$3.00
Microcontroller (ESP32)	Sensors and Processing	5	$0.82	$4.10
Raspberry Pi 4	Sensors and Processing	2	$61.99	$123.98
Signage Displays	Sensors and Processing	3	$4.96	$14.90
Power Supply Adapter	Power (Batteries)	1	$15.99	$15.99
Batteries	Power (Batteries)	8	$1.95	$15.60
Voltage Regulators	PCBs and Electrical	15	$1.82	$28.23
PCB for Sensors	PCBs and Electrical	10	$0.5	$5.00
Main PCB	PCBs and Electrical	5	$4.99	$17.8
Stencil	PCBs and Electrical	5	$7.00	$35.00
Components				$243
PCB shipping / Import Duties				$105
Total				**$660**

Work Distribution

Mark Rehn (EE)

Focuses on PCB design, PSU design, and MCU communications and hardware integration.

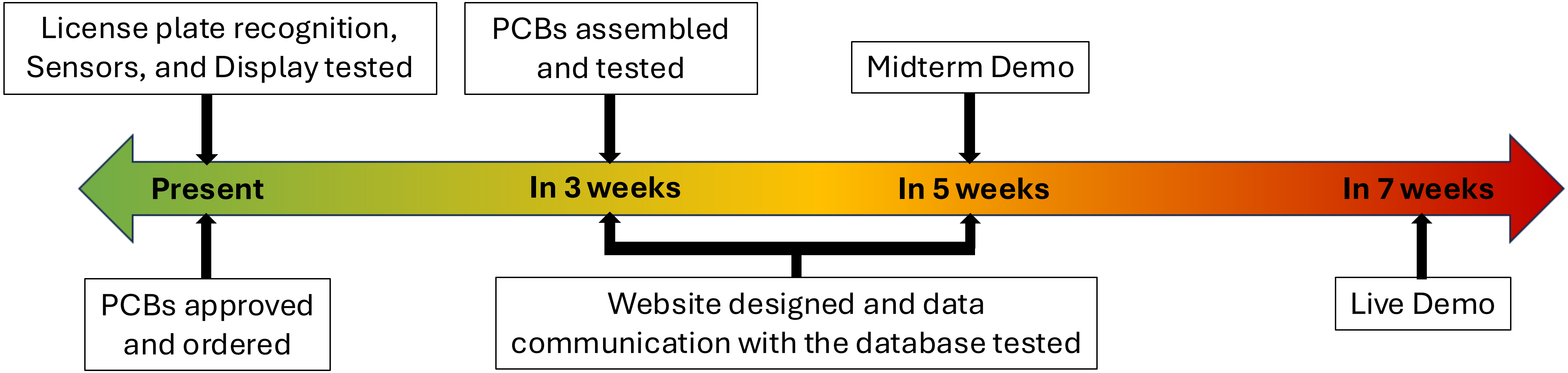
Chris Najem (CE)

Develops License Plate Recognition software, Manages Raspberry Pi/Camera, Database, Server, and web app design.

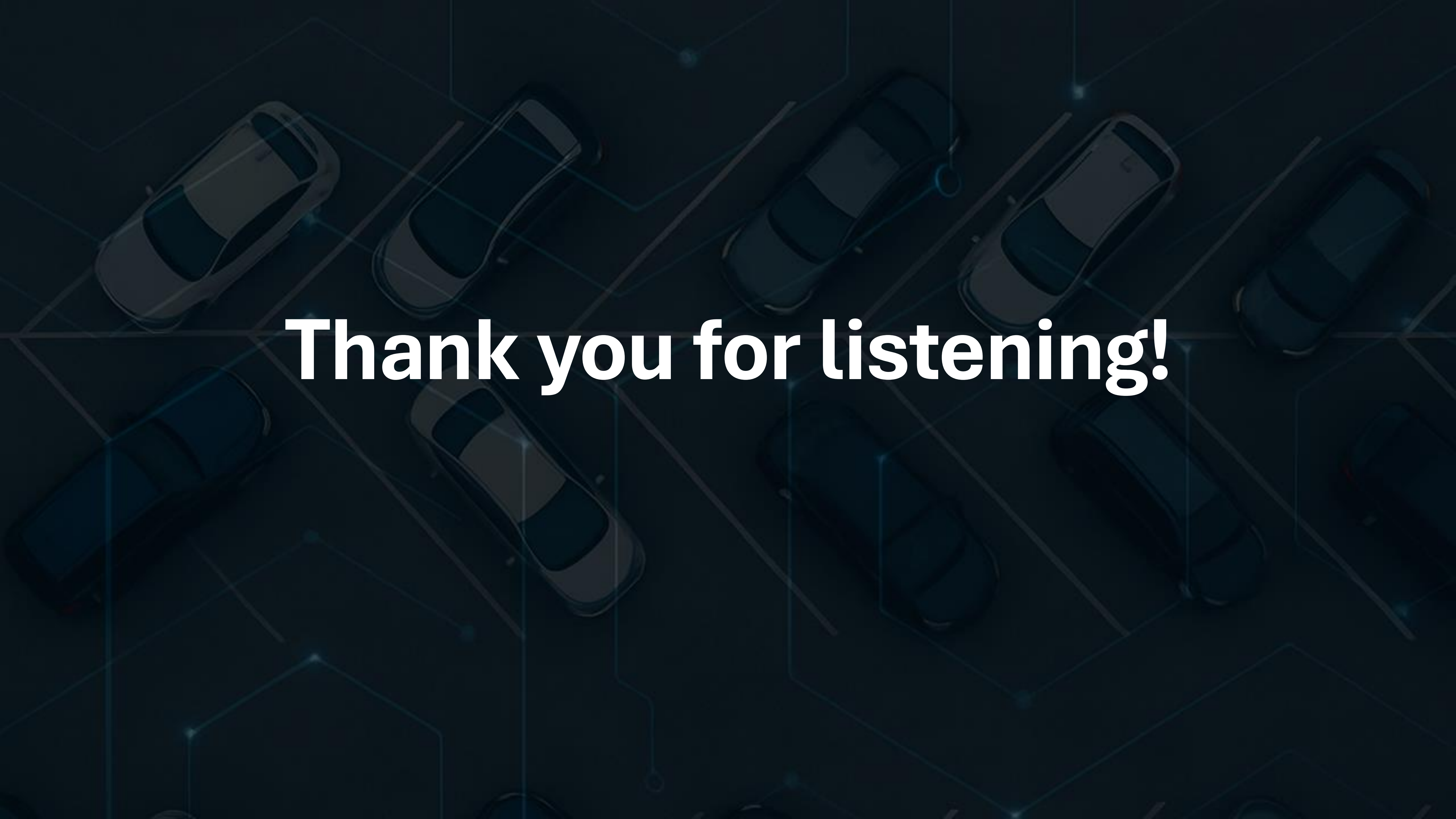
Tony Mai (CE)

Manages MCU connections for display, ultrasonic sensor/LED, and software for these components, web app design.

Progress and Future Milestones



- Assemble the PCBs to test the charge controller and the entire project by the midterm demo deadline
- Having the Parking Garage Management System in private parking lots in companies and/or universities



Thank you for listening!