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Senior Design I

Divide & Conquer Parking Garage Management System Group 11

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Chapter 2 - Project Description

Finding a parking spot in urban areas, colleges campuses and shopping centers, has become increasingly time consuming and a frustrating experience in a city's day to day life. Traditional parking systems contributes to inefficient fuel consumption, increased traffic congestion and driver stress. As cities grow, and with it the demand for parking, it become clear that a more efficient parking system is needed. The Parking Garage Management System is designed to address these issues by providing real time monitoring, in-garage parking navigation, license plate recognition for security enhancement, and online payment systems. This chapter will walk through the motivation behind this project, its goals, key features and a high-level design implementation.

2.1 Project Background and Motivation

Parking. It sounds like a simple task. Just pull in, find a spot and go on with your day. But in places like urban areas, college campuses, shopping and entertainment centers, finding a parking spot is anything but simple. You keep driving in circles scanning rows of cars while feeling your frustration rise with every pass. Parking has long been a challenging aspect of urban life. The process of searching for an empty parking spot often leads to frustration, wasted time and unnecessary fuel consumption.

With urbanization, traditional parking solutions have been proven inadequate in addressing these challenges. According to a study done by INRIX, a transportation analytics company, searching for parking costs the United States economy \$73 billion per year. On average American drivers spend 17 hours per year searching for a parking spot resulting in a \$350 cost per driver in wasted time, fuel, and emissions. These numbers only get larger in big cities, for instance in NYC drivers spend on average 107 hours per year searching for parking, costing \$2,243 per driver. Los Angeles trails NYC with 85 hours and \$1785 respectively.

The impact of not being able to find a parking spot isn't limited to financial consequences. Almost two-thirds of Americans reported that they feel stressed trying to find a parking spot, with 23 percent experiencing road rage after abandoning the trip due difficulty finding parking. According to Bob Pishue, senior economist at INRIX, "The search for parking, overpayments and fines is a \$96 billion problem in the U.S. To lessen the burden parking pain has on our economy and quality of life, drivers, parking operators and cities must adopt smart parking solutions."

Enter the Parking Garage Management System. It takes this everyday headache and turns it into an effortless experience. Imagine pulling into the parking garage and immediately knowing where to go to find an available spot. No guessing or moving around in circles scanning every row, just a straightforward path towards your destination. A smart parking system would provide real-time availability and directions for parking spots which can help alleviate the issue of driving in unnecessary circles trying to find parking. It's a small change with an enormous impact—not just on your day but on the environment and the flow of the city itself.

2.2 Goals and Objectives/Design Requirements

The Parking Garage Management System is designed to enhance efficiency, security, and user experience in parking facilities. Below is an outline of the goals and objectives:

Basic Goals (Must-Haves):

1. **Real-Time Monitoring:**
 - Ultrasonic sensors detect parking spot availability and update LED indicators (green for available, red for occupied).
2. **Navigation Assistance:**
 - Digital signage at the entrance displays available spaces, and a website/mobile app provides real-time updates.
3. **Security Enhancements:**
 - License plate recognition (LPR) cameras verify permits and generate alerts for unauthorized or overstaying vehicles.
4. **Automated Payments:**
 - Users can purchase permits via a mobile app or website, with real-time database updates.
5. **Admin Dashboard:**
 - Provides tools for monitoring occupancy, managing permits, and addressing alerts.

Advanced Goals (Desirable Features):

1. **Energy Efficiency:**
 - Use solar panels and a battery management system for sustainable power.
2. **User Notifications:**
 - SMS or app notifications for permit status and alerts.
3. **Data Analytics:**
 - Track vehicle patterns for optimizing operations.

Stretch Goals:

1. **Dynamic Pricing:**
 - Adjust prices based on demand.
2. **Advanced Security:**
 - Include vehicle attribute recognition and law enforcement integration.
3. **Outdoor Parking Support:**
 - Expand to outdoor lots with weather-resistant sensors

2.3 Description of Features/Functionalities

The Parking Garage Management System is designed to streamline the parking experience by integrating advanced hardware and software technologies. The system focuses on improving efficiency, security, and user convenience through the following features:

2.3.1. Real-Time Parking Availability

The system employs ultrasonic sensors installed in each parking spot to detect occupancy. These sensors provide real-time data to a central server, which updates the availability status on digital signage and the mobile application. LED indicators are installed at each parking spot, displaying:

- Green: Spot is available.

- Red: Spot is occupied.

This functionality minimizes the time users spend searching for parking spaces, improving overall user satisfaction and reducing traffic congestion in the parking garage.

2.3.2. Guided Parking Navigation

The system provides users with real-time navigation assistance through digital signage and an integrated website or mobile app. This feature is designed to optimize user experience and reduce the time spent searching for available parking. Key functionalities include:

- Digital Signage at Garage Entrance:
 - A large digital panel at the entrance displays the number of available spaces on each floor of the garage.
 - The panel updates in real time based on sensor data, ensuring accurate and up-to-date information for drivers.
- Website or Mobile Application:
 - A user-friendly platform (web or mobile app) shows the general number of available spaces across all garages connected to the system.
 - Real-time updates ensure users can plan their parking before arriving at the location.

This dual-layered navigation system ensures that users can make informed parking decisions even before entering the garage, improving convenience and efficiency.

2.3.3. Security Monitoring

The system leverages license plate recognition (LPR) technology to enhance security by monitoring vehicle activity and permit compliance at the entrance and exit of the parking garage. Key functionalities include:

- License Plate Recognition Cameras:
 - Cameras installed at the entrance and exit capture and identify vehicle license plates in real time.
 - The system cross-references the license plate with a parking permit database to verify authorization.
- Alerts for Unauthorized Vehicles:
 - If a vehicle does not have a valid parking permit, the system generates an immediate alert to local security personnel for prompt action.
 - Unauthorized vehicles are flagged in the system for monitoring and potential follow-up.
- Real-Time User Notifications:
 - For users who have previously registered their license plate, the system sends an SMS reminder immediately after the entrance camera recognizes a vehicle without a valid parking permit.
 - The reminder includes steps to quickly obtain a parking permit to avoid further issues.
- Extended Stay Monitoring:
 - The system tracks vehicles that overstay their allotted parking duration and sends alerts to local security, providing details about the vehicle and its extended stay.

By combining real-time monitoring, user notifications, and automated security alerts, this system ensures that only authorized vehicles can access the garage, enhances user compliance, and maintains a secure and efficient environment for all.

2.3.4. Admin Dashboard

The Admin Dashboard provides administrators with real-time control and monitoring capabilities to ensure smooth garage operations and efficient system management. This centralized interface is designed for ease of use and offers the following key functionalities:

- Real-Time Occupancy Monitoring:
 - Displays the current number of available and occupied spaces on each floor of the garage.
 - Includes a summary of overall occupancy across all connected garages.
- Vehicle Authorization Management:
 - Enables administrators to view, add, or update parking permits for registered users.
 - Provides a log of vehicles flagged for unauthorized access or extended stays, along with timestamps and incident details.
- System Alerts and Notifications:
 - Consolidates all alerts, such as unauthorized access, extended stays, or vehicles attempting to leave after operational hours.
 - Allows administrators to resolve alerts or escalate them to local security personnel.

The Admin Dashboard serves as the command center for the Parking Garage Management System, enabling seamless management, enhanced security, and data-driven decision-making for administrators.

2.3.5. Automated Payment System

The Automated Payment System simplifies the process of obtaining a parking permit through a user-friendly and efficient workflow, particularly benefiting users who do not have a parking permit when using the garage. This system eliminates the need for physical tickets and manual transactions. Key functionalities include:

- QR Code Access:
 - QR codes are strategically placed inside the garage for users to scan using their smartphones.
 - Scanning the QR code directs users to the system's website or mobile app, where they can quickly register their vehicle's license plate and purchase a parking permit.
- Flexible Parking Permit Options:
 - To accommodate a variety of user needs, the system offers multiple parking permit plans:
 - Daily: Ideal for one-time or short-term parking.
 - Weekly: A convenient option for users needing access for a few consecutive days.
 - Monthly: Cost-effective for regular users.
 - 6-Month: Mid-term option for frequent parkers.
 - Annual: Best value for long-term users.

- Each option is clearly displayed with pricing and details, making it easier for users to select the plan that suits them best.
- Secure Payment Integration:
 - The system supports multiple payment methods, including credit cards, digital wallets, and other secure gateways.
 - Payment receipts are automatically sent via email or SMS for user convenience.
- Real-Time Parking Permit Updates:
 - Once payment is completed, the system immediately updates the vehicle's status in the parking database.
 - This ensures seamless entry and exit for users, monitored by the license plate recognition cameras.

This automated payment system enhances accessibility for users without prior parking permits, streamlining their experience while ensuring efficient and secure parking management.

2.4 Existing Products/Past Projects/Prior Related Work

Thankfully, certain parts of our project have been done previously, and a few small companies offer specific features that our product has, but we are focused on putting these features into one product. These offerings have helped us with brainstorming what products users like and what could help with ease of use for both the user and the admin/security.

2.4.1 Disney Springs

One of the main inspirations for our system is from Disney, where their Disney Springs shopping location has multiple garages that make it extremely easy to find open parking spots. They utilize LEDs to indicate whether a parking spot is open or not, where the LED being green means that the parking spot is free while the LED being red indicates an occupied parking spot. They also have a sign that shows the number of open spots on each floor and once you are on that floor, they have signs on each row that show the number of open spots for that row. This allows users to save time since they do not have to go through each row to find an open spot, while also allowing security to check if there could be anyone staying past the closing time of that garage. Many customers who had to park in their garages are usually amazed at the system and how easy it makes parking, especially at a busy shopping center like Disney Springs. Systems like the ones in the Disney Springs Garages are quite common outside of the US, so many Americans would like to see more of this technology to make their life a little easier. We are borrowing the LED system to indicate open or taken parking spots and the signs for the number of open spots, whether per row or floor.



Figure 2.1: Disney Springs Garage LEDs and Signage

2.4.2 Parking Guidance System

While researching prior works, we stumbled upon a company called Parking Guidance Systems LLC, where their product resembles what we wanted to do. They are a company that specializes in teaming up with businesses that want their parking garages to have custom parking guidance solutions and seem to be based in the US. They use LEDs to also indicate free parking spaces for indoor parking and can create signs to show available parking, but one difference is that they also offer outdoor parking solutions, using sensors to show how many spaces are free in that parking lot. They also offer custom mobile apps for these parking garages for users to see real time information about the parking garage. A few locations in Texas and Oklahoma use their systems, where customers have stated that they do not have trouble finding parking due to these systems. We wanted to make an app and website before finding this company, but we will use their app features as a reference for our app and website features.

2.4.3 OpenALPR

Implementing AI to detect license plates is one of the conveniences we are striving to provide, whether it is to help the driver avoid a ticket or to help the security officer with notifying which cars do not have a permit. OpenALPR was one of the license plate detection software that we first stumbled upon and has many of the features we are looking for. Some of their features that interested us was the contactless payment system where the user's car is put into the database from the license plate and the user can pay for that car using the website. They also have a feature that can flag cars that have not paid for the permit and easy notification to security so they can ticket that car. Their database of vehicles includes not only their license plate, but also attributes of the vehicle like color, brand, etc. Numerous police departments in the country use their detection software to help with either traffic incidents or to help find specific vehicles that could be dangerous. We are focusing on just the license plate so our product will not focus on the vehicle attributes, but we will try and implement a system similar to how they flag cars that did not pay for a permit.

2.5 Engineering Specifications

The Parking Garage Management System integrates hardware and software to create a seamless parking solution. The hardware focuses on real-time data collection and system operation, while the software processes and presents this data for user interaction and administrative management. Together, these components provide an efficient and scalable solution to enhance parking convenience, security, and operational control.

2.5.1. Hardware Description

The hardware of the system is designed to ensure reliable and efficient operation through accurate data collection and communication. It incorporates components for detecting parking availability, monitoring vehicles, and managing power sustainably. These elements will work together to provide real-time updates and enable smooth integration with the software platform.

Key Hardware Features:

1. Edge Processing with the Microcontroller
 - Instead of sending raw data to the backend, the microcontroller will process sensor inputs locally to reduce network traffic.
 - A predefined threshold algorithm will determine if a parking spot is occupied before sending updates to the server.
2. Backup Power System for Critical Components
 - To prevent failures in case of power loss, a backup battery system will be implemented for:
 - License Plate Recognition (LPR) cameras.
 - Wireless communication modules.
 - This ensures security monitoring continues functioning even if the main power system fails.

Preliminary hardware components include:

- Ultrasonic Sensors - Detects parking spot occupancy and updates availability.
- License Plate Recognition (LPR) Cameras - Captures vehicle entry/exit data for security monitoring.
- Digital Signage & LED Displays - Guides drivers to available spaces in real-time.
- Wireless Communication Modules - Ensures seamless data transmission.
- Raspberry Pi - Handles image processing.
- Microcontrollers - Manages sensors, LED indicators, and real-time processing.
- DC 12V 5A Power Supply Adapter - Primary power source for the system.
- Battery Management System (BMS) - Regulates power distribution and optimizes battery efficiency.
- Backup Power Units - Ensures continued operation of critical components in case of power failure.
- Voltage Regulators - Provides stable power to all electronic components.

2.5.2. Software Description

The software provides the framework for integrating hardware data into an intuitive platform for users and administrators. It will manage real-time updates on parking

availability, permit handling, and secure payments, while enabling administrators to monitor and control system operations. Whether deployed as a mobile app, a website, or both, the software will be designed with scalability and user convenience in mind.

Key Software Features:

1. Machine Learning for License Plate Recognition
 - The LPR system will use a pre-trained deep learning model to improve accuracy.
2. Predictive Analytics for Parking Demand
 - The system will use historical parking data to estimate future demand trends.
3. Automated Ticketing for Violations
 - If a vehicle parks without a permit, the system will:
 - Capture the plate number.
 - Generate a violation report.
 - Send an alert to the admin dashboard.
 - This feature enhances security and compliance.

Preliminary software components include:

- Backend Server - Handles real-time data processing and database management.
- User Interface - Displays parking availability and handles permit purchases.
- Admin Dashboard - Provides monitoring, alerts, and analytics.
- Payment Gateway Integration - Ensures secure transactions and real-time permit updates.

2.6 Required Specifications

The table below outlines the key specifications for the Parking Garage Management System, detailing measurable criteria and highlighting specifications that will be demonstrable during the project.

Table 2.6.1 Specification

Specification	Value/Range	Description
Ultrasonic Sensor Accuracy	± 3 mm	Accuracy of ultrasonic sensors in detecting parking spot occupancy.
License Plate Recognition	$\geq 95\%$ (daytime) $\geq 85\%$ (nighttime)	Accuracy of LPR cameras in identifying license plates under varying lighting conditions.
System Uptime	$\geq 99.9\%$	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	$\geq 85\%$	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.

2.6.2 Hardware Diagrams:

The diagram below outlines the power system architecture of the project, focusing on the key components and their connections. The Power System Hardware Diagram (Figure 2.2) illustrates how the PowerPath Controller connects to both the Power Supply and the Battery Management System (BMS), ensuring efficient power transfer across the system. The PowerPath Controller plays a central role in managing the transitions between primary and backup power sources. Additionally, the Charger Controller is integrated into the system to regulate charging, ensuring safe and efficient charging through the BMS. The diagram also shows the use of voltage regulators for the MCU and Raspberry Pis, ensuring that each component receives the appropriate voltage for stable operation

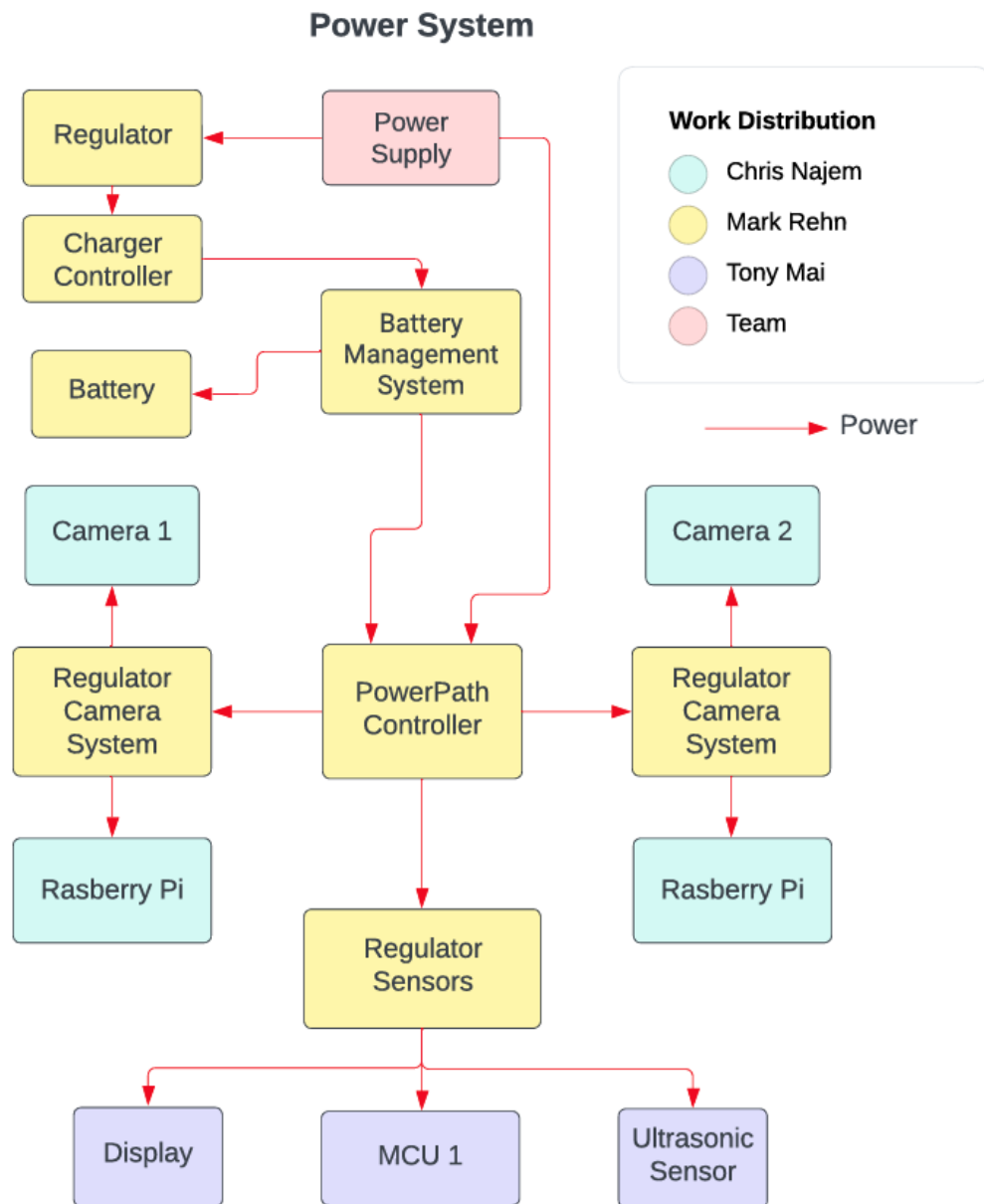


Figure 2.2: Power System Hardware Diagram
by Authors

The Data Communication Hardware Diagram (Figure 2.3) illustrates how data flows between the critical components of the system. It shows the interactions between the MCU, Raspberry Pis, Cameras, and Ultrasonic Sensors to ensure proper coordination across the system. The diagram highlights how these components communicate through digital signals, RF communication, and data communication, enabling real-time updates on system status, such as spot occupancy and license plate detection. This data flow is crucial for maintaining smooth operation, ensuring that information is consistently shared across the system for accurate monitoring and control.

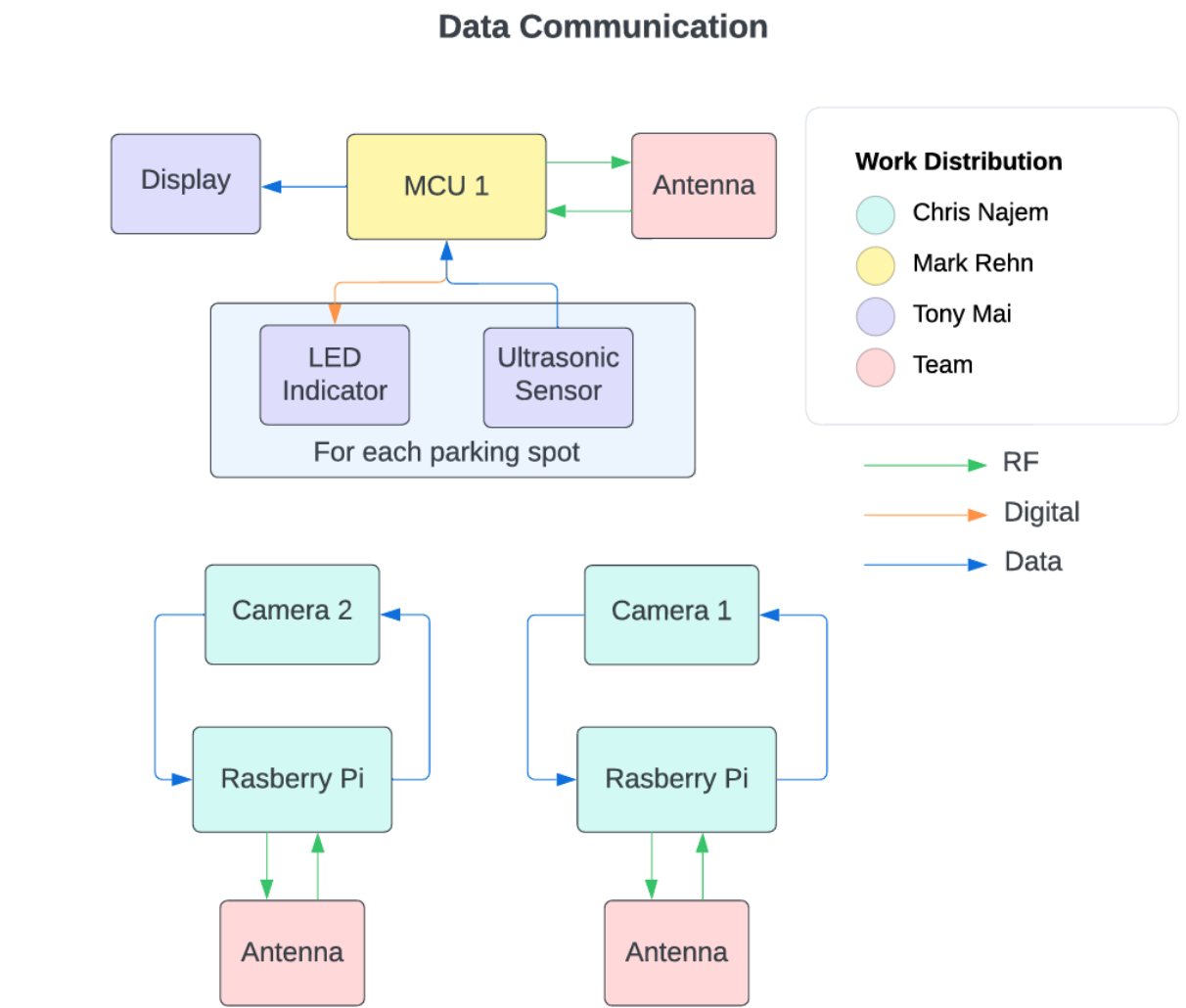


Figure 2.3: Data Communication Hardware Diagram
by Authors

2.6.3 Software Diagrams:

The below diagram outlines the operational flow of the parking garage management system from a software standpoint. It details how the system integrates and processes license plate detection, spot occupancy detection, and security enforcement. The system begins by waiting for a signal from either the cameras or ultrasonic sensors. If the entry camera detects a license plate, it checks against the database to determine whether the car has a valid permit or if it is unauthorized to enter. If the vehicle doesn't have a valid permit, or is unauthorized to enter, it will trigger a security notification, otherwise it will proceed with no issues. From the opposite side, an exit camera will also detect the license plate at the point of exit. If a car's license plate was recorded at the entry but not at the exit before the parking closing hours, then it will also trigger a security notification. Simultaneously, ultrasonic sensors monitor every spot occupancy status while updating the overhead LED, LCD screen, and the in-app occupancy tracker.

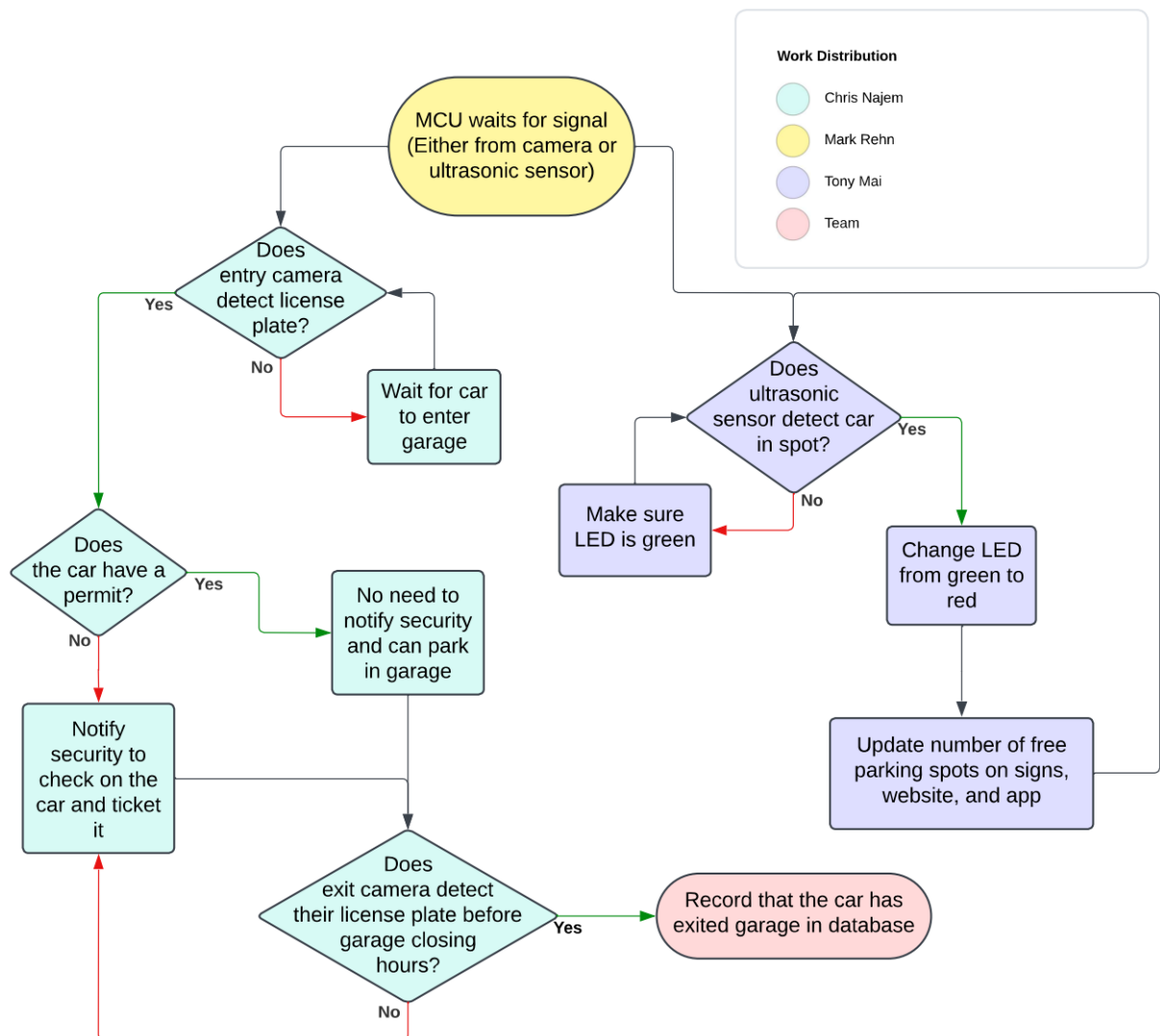


Figure 2.4: Software Diagram
by Authors

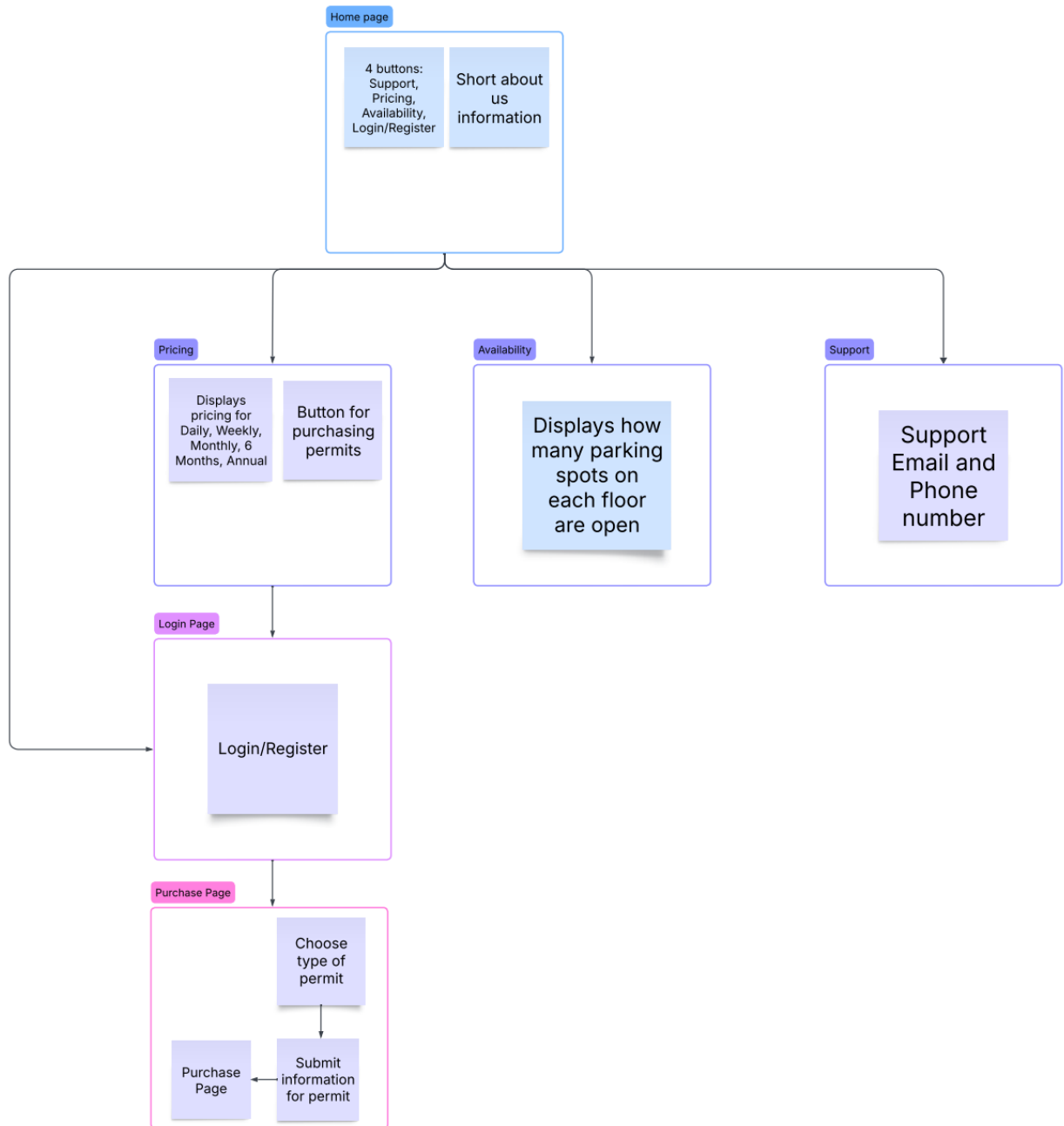


Figure 2.5: Website Diagram
by Authors

2.7 House of Quality

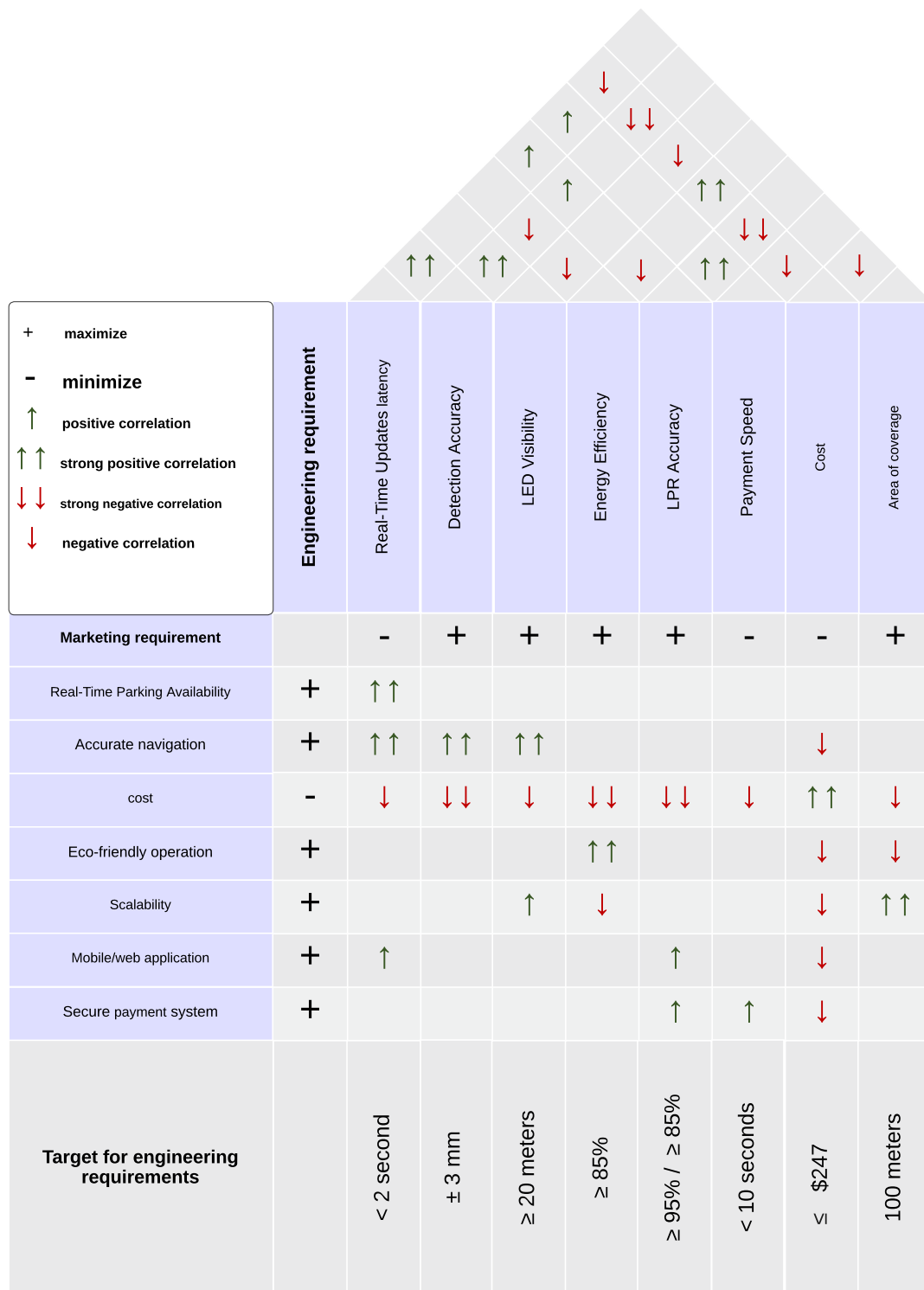


Figure 2.6: House of Quality by Authors

Chapter 3 - Research and Investigation

In this chapter, we explore the key technologies and hardware parts required in the Parking Garage Management System. For every selection, various options were evaluated to determine the most efficient, scalable, and cost-effective solution to be used in our system. The selection process prioritizes real time data processing, seamless integration, energy efficiency, and system reliability. By going through detailed research and comparisons, we will be able to establish the foundation to implement a robust system with optimal functionality.

3.1 Technologies

3.1.1 Database Selection

The database is a critical component in the license plate recognition system where it is responsible for storing the license plate data, timestamps, user accounts and other features that can be added into our system. The selected database must handle a high volume of incoming data from multiple cameras, while simultaneously supporting fast read and write operations. In this section we will explore three different kinds of databases: MySQL, MongoDB, and PostgreSQL comparing their features.

3.1.1.1 MySQL

The database is a critical component in the license plate recognition system where it is responsible for storing the license plate data, timestamps, user accounts and other features that can be added into our system. The selected database must handle a high volume of incoming data from multiple cameras, while simultaneously supporting fast read and write operations. In this section we will explore three different kinds of databases: MySQL, MongoDB, and PostgreSQL comparing their features.

1. MySQL creates a database for storing and manipulating data while defining the relationship of each table
2. Clients make requests by typing specific SQL statements
3. The server application will respond with the requested information, and it will appear on the client

One of MySQL's main advantages is its capabilities to perform fast read operations, making it a great choice for applications that require real time updates. MySQL also supports indexing which helps in efficiently managing relationships between vehicle entries, timestamps and user accounts. However, the table format of MySQL doesn't come without its drawback. The table-based storage format of MySQL can lead to internal fragmentation especially as the database grows. Since tables have a fixed structure, that means each row and column must be allocated a fixed set amount of storage at creation. If a column is not used for a particular row, then that space reserved for this entry will still be occupied for future use, leading to a lot of wasteful storage.

3.1.1.2 MongoDB

Another database that was explored is MongoDB. MongoDB is a NoSQL database that utilizes document-based storage making it well suited choice for applications with dynamic

data with a lot of updates and delete operations. Unlike SQL databases that rely on a preallocated fixed sized tables, a NoSQL database uses JSON like documents where data is stored in structured like format. Since MongoDB uses structure-like documents to store data, that means there will be no internal fragmentation and only the required storage will be allocated. This flexibility is particularly an advantage in real time applications, like a license plate recognition system, where the structure may constantly vary with every entry.

Another key advantage of MongoDB is its ability to handle large scale write operations with support to horizontal scaling where data is distributed across multiple nodes to ensure high availability and performance. Additionally, MongoDB utilizes a built-in aggregation framework that makes it a powerful tool for data processing. This makes MongoDB an excellent choice for applications that require real-time processing like the license plate recognition system. On the other hand, a MongoDB database comes with some advantages. By not being a relational database, like an SQL database, MongoDB lack the support to perform a join operation between multiple collections meaning combing different data structures (formally known as collections) is a much harder task compared to a relational SQL database.

3.1.1.3 PostgreSQL

PostgreSQL is one of the most popular open-source relational databases. Its development dates all the way back to 1986 at UC Berkley under the direction of Michael Stonebreaker. Like other relational databases it stores data in tables columns and rows and uses structured query language (SQL) to read and write data. However, it is technically an object relational database which means can create its own custom data types to store objects with properties and support advanced features inheritance and polymorphism. When running data, it runs fully ACID (Atomicity, Consistency, Isolation, Duration) transactions but also adds its own variations to it by using what is called Multiversion concurrency control which gives each transaction a snapshot of the database. This allows multiple transactions to run at the same time without traffic jams or locks. Developers also love its extensibility. Queries can be reused by writing stored procedures and it even supports languages beyond SQL like python and C.

What is good about PostgreSQL is that it supports an exotic data modeling options, like arrays can be used by putting brackets in front of a type but then we can make a two-dimensional array by another set of brackets. PostgreSQL also supports Json data type to handle unstructured data. It also supports Key value pairs with extensions like H-store. Every table has a unique primary key and we can create relationships by storing the primary key from one table as the foreign key on the other. However, despite PostgreSQL versatility where it can handle both relational and semi-structured data, it is relatively a more complex system to deal with compared to MongoDB or MySQL.

3.1.1.4 Final Selection

After comparing the above discussed databases, we decided to use MongoDB in our project as the primary database. MongoDB provides a good balance between flexibility, scalability and ease of use. For our project the main use of the database is to store the detected license

plates, accompanied by timestamps and users accounts. All the above databases have the required capabilities to perform such operation but MongoDB's flexibility with its ability to store semi-structured data more efficiently, coupled with the fact that it is one of easiest databases to learn and use, made it our primary database of choice. By Using MongoDB, the license plate recognition system can achieve scalability, flexibility and high speed read-write operation.

Table 3.1.1: Database Comparison

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

3.1.2 Server Selection

The server is one of the most crucial parts in our system, without it the whole system will not be able to function. The server's main responsibility is to manage the data flow between the physical sensors/cameras, the database and the front-end application. When selecting a server, it is important to take into consideration its features like scalability, real-time data processing speed and ease of deployment. Another key feature to consider is a server's uptime, which is the measure of time a server remains connected to the internet and updates its data. This last feature, uptime, is the most crucial criteria to consider since for every second the server is down that will simultaneously equate to our system being down and unusable. In this section we will explore different types of hosting environments split between local server and cloud-based servers' solutions.

3.1.2.1 Local Server

A local server refers to the type of hosting environment where the server runs on a dedicated-on premise machine such as a raspberry pi or a high-end computer. One of the

main advantages of such a system is its reliability, especially in places with internet connectivity issues. Another key advantage of a local server is its low latency data processing. By keeping the server where the database is running on-site, this minimizes the distance data packets have to travel over the internet leading to low latency, improving performance and mitigating any problems caused by internet connectivity issues. This system is particularly useful in applications that require real-time processing such as our license plate recognition system where data should be immediately processed with minimum delays in both directions. Additionally, by relying on a local server we can get the added benefit of data security by minimizing transferring data over the internet and restricting server internet access only when necessary. However despite having numerous benefits, a local server can have a list of potential downsides. To begin with, any type of a server requires constant maintenance and periodic updates; by utilizing a local server this responsibility falls solely on the developers of the system, whereas by using a cloud-based server developers can offshore such responsibility to the hosting provider. Another disadvantage of a local server is scaling. Scaling a local server requires installing additional physical hardware to accommodate the increase in storage and processing demand, this increases the time gap between demand requests and actual deployment. While on the other hand, by using a cloud-based server, demand can be immediately met by scaling operation up or down to always have the perfect balance between storage supply and demand.

3.1.2.2 Cloud-Based Server

Cloud based servers are servers that use third party providers to deploy and maintain them. These systems provide scalability, automatic updates and region based access. Below we discuss three of the most popular cloud-based server solutions out there.

3.1.2.2.1 MongoDB Atlas

MongoDB atlas is cloud-based server that is supplied by the same company that provides MongoDB database, delivering a fully optimized environment between MongoDB server and database. MongoDB utilized existing cloud providers like AWS, Google Cloud and Microsoft Azure, leading to increased reliability and accessibility. One of its key features is its dynamic scaling that can be used to handle fluctuations in demand. When demand increases or decreases, so does cloud storage, providing optimal performance where supply meets demand. MongoDB atlas provides users with 3 subscription plans. The first plan, despite its limited storage of 512 MB, is free of charge. This makes it an ideal solution, for learning and exploring MongoDB and deploying limited systems to test it. The second subscription tier is a pay as you go system, billed at \$0.08 per hour. This plan tier provides 10 GB of storage and 2GB of Ram, making it an ideal solution for limited use applications like our parking garage management system project. The third and final tier is also a pay as you subscription plan costing \$0.0011 per hour, for a max of \$30 per month, providing up to 5 GB of storage with a shared RAM. One of MongoDB's key features is its end-to-end encryption, and a centralized web-based dashboard to manage the database pragmatically.

3.1.2.2.2 Amazon Web Services (AWS)

Amazon web services (AWS) is one of the most popular servers available. A widely used setup involves using EC2 (Elastic Compute Cloud) for hosting the server and RDS (Relational Database Service) for database management. An EC2 instances provide

developers with a dedicated virtual server that can be fully customized and where developers can choose their systems features like storage, and computing power. AWS' key features are its widespread availability among different countries and regions, decreasing latency and increasing performance. Recently AWS also started incorporating its AI analytics tool, called AWS Recognition, which can enhance and speed up developer's experience. However, despite AWS positive features, it is still a relatively complex system to set up and manage, where developers are responsible for their own updates, backups and scaling. This complexity makes AWS difficult to recommend, especially for developers of small applications like our parking garage management system project. Compared to MongoDB that is easy to use, and has automatic scaling, AWS is, on the other hand, a more complex system that is dedicated to developers of big applications.

3.1.2.2.3 Google Cloud Platform

Another cloud-server option available is Google Cloud Platform that offers a virtual server for hosting databases and applications. Just like AWS, Google Cloud platform has a global presence of datacenters in multiple counties and regions making it available to a lot of local developers that care about low latency. Although AWS is still the most widely available cloud server, Google Cloud Platform is a close second and in most cases a replacement to AWS. Google Cloud Platform main advantage over other cloud server platforms is its integration of TensorFlow, which is an AI framework that make deep learning application easier to build. On the flip side, Google Cloud Platform non straightforward pricing coupled with its low integration and support make it a non-suitable option for a lot of applications and systems. Google Cloud Platform requires a lot of expertise to setup and manage, coupled with pricier hosting plans makes it non-viable option for small scale systems like our parking garage management system project.

3.1.2.2.4 Final Server Selection

After looking at different server options, we decided to use a cloud-based hosting environment. MongoDB Atlas was selected as the best server that provides a good balance between ease of use, affordability, scaling, and security. Since our project requires a relatively small-scale deployment, dealing with the complexities of top cloud-based providers like AWS and Google Cloud is not worth it. MongoDB Atlas is the perfect solution for our project, especially with its seamless integration of MongoDB which is our database choice.

Table 3.1.2: Server Selection Comparison

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)	Moderate (Cloud-Based Security)

			Custom Security Configurations)	
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

3.1.3 Parking Sensors

As more cities get larger and with the increase in population comes an increase in cars, many places have begun to create more smart parking systems to help aid people by making it easier to find parking spaces in parking garages. Two common technologies used as parking sensors are ultrasonic and geomagnetic sensors. We will be focusing on those two sensors and why we decided to ultimately choose the ultrasonic sensors for our project.

3.1.3.1 Ultrasonic Sensors

Ultrasonic sensors rely on sound waves to detect objects in front of the sensor. They work by emitting sound waves from the sensor and measuring the time it takes for those soundwaves to reflect off an object back to the sensor, where it then takes that time and uses it to calculate the distance of the object from the ultrasonic sensor. This makes ultrasonic sensors a very good choice for object detection, which is why ultrasonic sensors are used in many applications, such as parking sensors for cars to detect objects in front or behind the vehicle or in robotics to allow the robots to detect obstacles and move past them.

Advantages:

- Accurate in detecting vehicles in designated parking spots
- Cost-effective and widely available
- Can be mounted on ceilings or walls to monitor individual parking spaces
- Often used in parking guidance systems

Disadvantages:

- Can struggle with false detections like people or shopping carts
- Limited range may require multiple sensors per space
- Susceptible to noise/weather interference

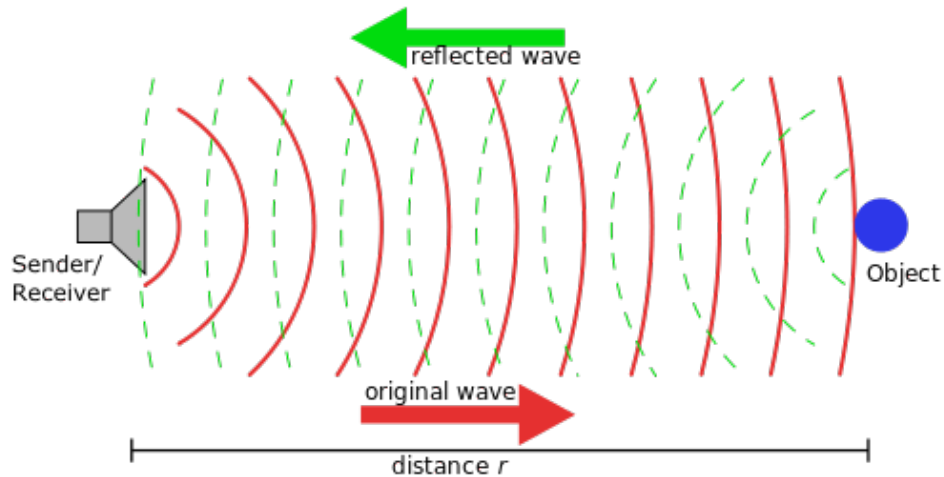


Figure 3.1: Ultrasonic Sensor Operation

https://www.teachengineering.org/lessons/view/umo_sensorswork_lesson06

3.1.3.2 Geomagnetic Sensors

For most parking spot solutions, geomagnetic sensors are generally used more since they make sure that it is a car that it senses and not anything else blocking the parking spot like a human or trash can. They work by detecting changes in the magnetic field near the sensor, so cars that go over these sensors will change the magnetic field in the area, prompting the sensor to detect the car above it. Due to the big metal bodies of cars, the geomagnetic sensors are usually accurate as a big metal body will surely be detected from those sensors. Since these magnetic sensors are typically designed for outdoor use as well, they are designed with weatherproofing in mind. These geomagnetic parking sensors have been used for quite some time, so many existing products are available out there, though not as inexpensive as an ultrasonic sensor.

Advantages:

- Embedded in the ground, less intrusive
- Does not detect other objects like people or carts
- Low maintenance after installation
- Can handle weather interference
- If wireless, installation can be a breeze

Disadvantages:

- Wired installation can require modifying the parking garage floor, which can be expensive if they were not built with these sensors in mind
- Calibration to avoid interference from other metal objects
- Most parking geomagnetic sensors are battery powered and designed to be weather resistant, which means you would have to replace the sensors if the battery died
- Not as cheap as ultrasonic sensors

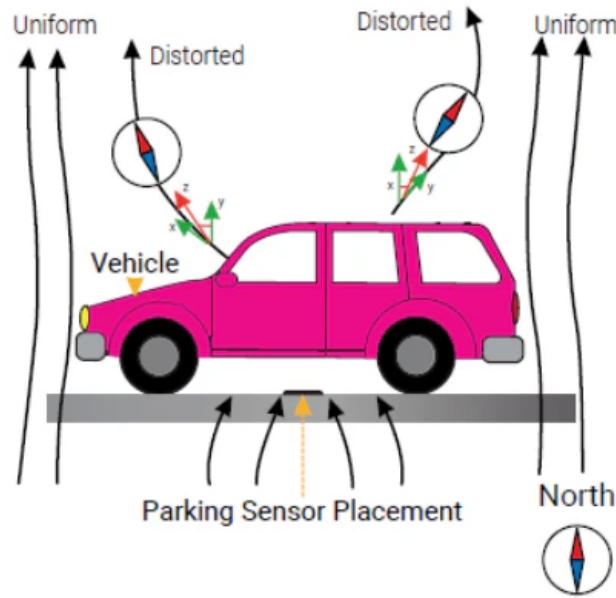


Figure 3.2: Geomagnetic Sensor Operation

<https://www.elecomes.com/products/tbs-201-turbo-dual-mode-radar-and-geomagnetic-parking-sensor?variant=35494293930144>

3.1.3.3 Why Ultrasonic Sensors?

Since our project mainly focuses on parking garage management solutions, we will not have to worry about the weather being a factor that can affect ultrasonic sensors. We also want to provide a cheaper alternative as ultrasonic sensors can be cheaper than geomagnetic sensors. Some ultrasonic sensors can be as low as \$4, while geomagnetic sensors usually start above \$120 for a pack of 4 sensors, making each geomagnetic sensor cost about \$30. Since ultrasonic sensors can be added anywhere on the parking spot (in front, ceiling, under, etc), that means adding them to existing parking garages will be a lot easier than trying to implement geomagnetic sensors, especially since they are embedded into the ground and will need to possibly dig up or alter the existing environment to implement them. Another reason we decided to go with ultrasonic is that for wireless geomagnetic sensors, they are usually battery powered. Since they are also weatherproof as well, that means that changing the battery is not an option, so the sensor will have to be replaced once it dies. This is usually okay since these sensors last about 5 to 10 years, but it is one of the reasons why we decided to go with ultrasonic sensors so we do not have to worry about switching batteries or swapping sensors out unless they fail, which is very unlikely as some ultrasonic sensors can last as long as 22 years.

Table 3.1.3: Ultrasonic Sensor vs Geomagnetic Sensor

Features	Ultrasonic Sensor	Geomagnetic Sensor
Detection Method	Emits soundwaves and detects time it takes to bounce back, using that time to calculate	Detects magnetic field change when vehicle parks on top of sensor

	distance	
Installation	Can be installed on the ceiling, walls, or ground, wireless or wired	Can only be installed on the ground, wired
Interference	Susceptible to noise or weather interference	Not susceptible to noise and weather interference
Cost	Can be very cheap	Not very expensive but also not very cheap
Detection Range	Usually detects when the vehicle is on the parking spot	Detects from a wider range, especially if mounted on walls
Power	If wireless, battery powered	Wired
Maintenance	Will need to replace sensor when battery dies, only 5-10 years	Since it is wired, only replace items if they fail
Lifespan	Until battery dies, 5-10 years	Up to 22 years

3.1.4 Processing Unit

When talking about processing units, there are a few options that we are able to choose from. Two types of processors that we will be looking at are microcontrollers and microprocessors. For our project, we researched the difference between the two to decide which would fit our needs.

3.1.4.1 Microprocessors

Microprocessors (MPU) are essentially smaller central processing units (CPU). Unlike microcontrollers, the memory and peripherals are not on the same chip as the CPU, so communication between those components is not as fast as microcontrollers. They are better with more computational tasks compared to microcontrollers since they are usually more powerful, allowing them to actually perform advanced tasks like machine learning.

3.1.4.2 Microcontroller

Microcontrollers (MCU) are meant for embedded systems that deal with real time tasks and do not need to use much power since those tasks aren't that computation heavy. They integrate the CPU, memory, and peripherals into one chip. This allows them to quickly

perform simple tasks, which makes them perfect for specific real time tasks like making sure the LED changes immediately when detecting a car or not.

3.1.4.3 MPU or MCU?

One of the main features of our project is license plate detection using AI/ML. Since MCUs are designed for low power, less complicated tasks, not only will we need to choose a processor for real time tasks, but we will also need another MPU to handle the license plate detection. So, we decided to split off those two parts of our project with one MCU to handle that real time part with the LEDs and sensors and one MPU to handle the camera license plate detection with machine learning. The MCU should be able to handle real time events very well due to the integrated nature of the chip, meaning the communication inside the chip is quick, while the MPU should be great at handling the license plate detection with machine learning due to its higher processing power.

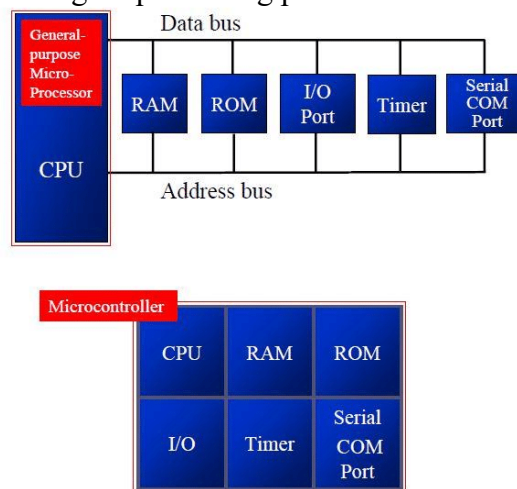


Figure 3.3: Microprocessor vs Microcontroller

https://www.researchgate.net/figure/Block-Diagram-of-Microcontroller-and-Microprocessor_fig1_305698918

3.1.5 LEDs

For each parking spot, there needs to be an LED to show whether the parking spot is available or taken. This LED needs to be bright enough for cars to see when they are looking down at the rows of parking spots so that they can easily spot a free parking spot. This means we have to look for LED technologies that will ensure adequate brightness since this will be our main goal for choosing which type of LED we will go with.

3.1.5.1 DIP LEDs

Dual In-Line Package (DIP) LEDs are your typical, simple LEDs that have two metal legs with the LED diodes encased inside a transparent plastic housing. These LEDs are mainly used in simple circuits and prototyping due to their ease of use with the metal legs, allowing it to be used in breadboards and easily soldered. These types of LEDs are not as bright as other types of LEDs, but they are durable and last a long time, compared to other LED technologies. They are an older technology, but they are still used in many items, so they aren't a bad option for our use case. These DIP LEDs are very inexpensive as other LED technologies have surfaced, so they are a great option for low-cost LEDs.

3.1.5.2 SMD LEDs

Surface-Mounted Device (SMD) LEDs are a lot smaller compared to the typical DIP LED. Each SMD LED can have RGB capabilities within each chip, so we wouldn't have to use two DIP LEDs for red and green, instead we could just have one very bright SMD LED that can switch between red and green. SMD LEDs are also typically brighter and more efficient than DIP LEDs, making them one of the top options for our use case since there will be SMD LED options that are bright enough for our parking garage. SMD LEDs are soldered and attached to the surface of the PCB, so using it for our prototype will not be viable but we can always use DIP LEDs just for prototyping and SMD LEDs later on.

3.1.5.3 COB LEDs

Similar to SMD LEDs, Chip On technology Board (COB) LEDs are a lot smaller than the DIP LEDs, but COB LEDs have the ability to be even smaller than SMD LEDs and that is due to the layout. They are able to fit multiple diodes into a single PCB board, allowing it to be a lot brighter than using SMD LEDs in the same area. Though since this LED technology is so advanced, it is a lot more expensive compared to SMD LEDs and are meant more for high resolution displays like TVs, laptops, and monitors.

3.1.5.4 Which LED technology?

Since we want the LED on top of the parking spot to be bright enough to see during the daytime in a parking garage, we decided on using SMD LEDs as there are some chips that can get very bright, as well as having the option to use one chip for multiple colors. Since COB LEDs are so expensive, they are ruled out as being an option for the project due to one of our hopes of reduced cost. SMD LEDs have been used for a while now, so they are not as expensive COB LEDs and some SMD LEDs can be found for about the same price as some DIP LEDs, so this makes SMD LEDs our pick for the LEDs, especially considering they can be a lot brighter than DIP LEDs. Having worked with SMD LEDs on a PCB as well, it makes things a lot easier too since we have had prior experience with those types of LEDs.

3.1.6 Display

In our project, we wanted to enhance the ease of use for the customers. One of the items we thought about was a display that shows either how many empty parking spots there are in the parking garage or how many empty spots there were in that row. For our display, we want adequate brightness so that even if it is daylight out and sunlight enters the parking garage, the displays should still be visible to the customer. We are also just going to put up numbers on the display so it does not have to be limited to displays that can also show text and images. If possible, we would like to have a more efficient display so that it does not drain the backup battery system.

3.1.6.1 LED Display

LED displays are one of the most common display technologies used currently. Most of our phones, TVs, and monitors use LED technology, which are very beneficial for providing high quality and bright images. We saw that there were a couple types of LED displays, like 7-segment or dot matrix displays. 7-segment LED displays were made to only display numbers, so they are very limited but that should not be a problem with our

use case for these displays. Dot matrix LED displays are more like the typical display for electronics, where they have a grid of LEDs arranged in a rectangular form. They can display anything they want; they just need to change the LED diodes on or off so that it forms that image. One of the problems we were looking to tackle would be visibility, so brightness is one of the most important aspects of the display. LED displays are typically brighter than LCD displays, due to the fact that the LEDs actively emit light, instead of using low powered backlights like LCDs do. For durability and maintenance, LED displays typically have a lifespan of about 100,000 hours and require less maintenance than LCDs.

Advantages:

- High brightness, readable in daylight/night
- Long lifespan
- Less maintenance
- Can replace individual LED Diodes

Disadvantages:

- Limited color options
- 7-Segment displays are limited to numbers
- Upfront cost can be higher for larger displays

3.1.6.2 LCD Display

LCD displays are very common for low power applications, which can be good for our project since there is a BMS system for backup power. Unlike LED displays, LCD displays typically have a backlight on the whole display, where a liquid crystal layer allows or blocks light to pass, allowing it to make an image. LCD displays can be more energy efficient than LED displays, while being able to display the same things as a dot matrix LED display. Our members have used an I2C LCD display before, so that is why we looked at LCD displays as an option for our project. LCD displays are usually not as bright as LED displays, so visibility when the sun is out could be a problem. LCD displays typically have a lifespan of about 50,000 hours, so about half the lifespan of an LED display.

Advantages:

- Lower power usage than LED displays
- Can be more energy efficient than LED displays
- Cheaper

Disadvantages:

- Less bright than LED displays
- Lower lifespan compared to LED
- Will have to replace whole screen if it acts up

3.1.6.3 LCD or LED?

Due to the brightness advantage of the LED Display and the lifespan of it, we are choosing that as our display to show the number of free parking spots in the parking garage. Many parking garages that implement this type of display mainly use LED displays as well, so it

has been proven to work well and reliably. We can use an LCD display to test our prototype, but the final product will incorporate an LED display.

3.1.7 Power Supply

A power supply is one of the most essential components of an embedded system, as it ensures that all connected devices receive a stable and regulated voltage to function properly. Without a reliable power source, fluctuations in voltage or current can cause system malfunctions, reduce component lifespan, and, in extreme cases, lead to permanent damage. The selection of the power supply is particularly important in our project, as it not only needs to power the charger controller, which regulates the charging process of the Battery Management System (BMS) and backup battery pack, but also must be able to deliver power to the power path controller, which determines whether the system should draw energy from the primary source or switch to backup power. In addition to power stability, several other factors need to be considered when choosing the ideal power supply technology. These include efficiency, heat dissipation, response time, size, cost, and safety features. Given these requirements, we evaluated three main power supply technologies:

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

Table 3.1.4: Power Supply Technology Comparison

Specifications	Linear Power Supply	Switching Power Supply	Battery-Based Power Supply
Efficiency	Low	High	High
Size	Large	Compact	Large
Heat Dissipation	High	Low	Moderate
Response Time	Fast	Fast	Delayed (battery switching time)
Complexity	Simple	Moderate	Complex
Cost	Low	Moderate	High
Backup Power	No	No	Yes
Best Use Case	Low-power	High-efficiency	Portable systems

3.1.7.1 Linear Power Supply

A Linear Power Supply works by regulating voltage through a transformer and linear regulator. The primary advantage of linear supplies is that they produce a clean, stable output voltage with very low ripple. This makes them ideal for powering sensitive

electronics that require a stable voltage without fluctuations or noise, such as audio equipment or analog circuits. However, linear power supplies are inefficient compared to switching power supplies because they dissipate excess energy as heat. This is particularly problematic when the difference between the input and output voltage is large, as the power loss increases. One of the key drawbacks of linear power supplies is their low efficiency, typically around 40-50%, meaning they waste a significant amount of energy as heat, requiring larger heatsinks for cooling.

3.1.7.2 Switching Power Supply

A Switched Power Supply (SMPS), also known as a Switching Regulator, uses a different method to regulate voltage by rapidly switching the input voltage on and off using transistors. It converts the input energy into high-frequency pulses, which are then filtered to provide a stable output voltage. The key advantage of switched power supplies is their high efficiency (typically between 85-95%), meaning less energy is lost as heat. This makes them much more efficient than linear power supplies, especially for high-power applications. SMPS systems are also compact, lightweight, and versatile, making them ideal for applications where size and efficiency are critical. They can step up (boost), down (buck), or invert the voltage, providing more flexibility compared to linear regulators. However, they do introduce some electromagnetic interference due to the high-frequency switching, which can affect sensitive components unless properly filtered.

3.1.7.3 Battery-Based Power Supply

A Battery-Based Power Supply utilizes batteries to store and provide energy. The Battery Management System (BMS) regulates the charging and discharging process to ensure safe and efficient operation of the battery. Battery-based supplies are ideal for portable electronics or systems where external power sources are not available. However, battery life can be a limitation depending on the battery chemistry and system power requirements. The efficiency of battery-based systems is generally high, but they are limited by battery capacity and may require recharging after a certain period. Additionally, battery-based systems require an integrated charging circuit and monitoring system (such as a BMS) to ensure that the battery is charged efficiently and protected from overcharging or deep discharge.

3.1.7.4 Power Supply Technology Selection

After evaluating the different power supply technologies, Switching Power Supplies (SMPS) are the best choice for our project. They offer high efficiency, compact design, and low heat generation, making them ideal for powering the charger controller and power path controller, ensuring smooth transitions between the primary power source and backup power. The Linear Power Supply was ruled out due to its low efficiency and high heat dissipation, while the Battery-Based Power Supply is unnecessary given our existing battery backup solution. Overall, SMPS technology provides the most efficient and cost-effective solution for our system's power needs.

3.1.8 Voltage Regulation

Voltage regulation is a critical part of any electronic system. It ensures that all components receive a stable voltage, which is crucial for their proper operation. Fluctuations in voltage can lead to system instability, incorrect readings, or even damage to sensitive components.

This is especially important in systems powered by unregulated sources, such as batteries, where the output voltage can vary based on charge levels. Proper voltage regulation ensures that even if the input fluctuates, the output voltage remains consistent and within the required specifications. In our project, multiple voltage regulators are needed to handle different voltage requirements and input conditions. Since we may be switching between battery and mains power, the regulators must handle variations in input voltage while maintaining stable outputs. For example, devices like the Raspberry Pi and ultrasonic sensors require regulated 5V outputs, while the ESP32 requires a 3.3V output. Additionally, the charger controller will need a 12.6V output to charge the 3S lithium-ion battery pack. In this section, we will compare two key technologies for voltage regulation, Linear Voltage Regulators and Switching Voltage Regulators. These two types of regulators are most commonly used in embedded systems, and understanding their operating principles and advantages will help us choose the right technology for each application.

- **Linear Voltage Regulators:** Linear regulators work by dissipating excess energy as heat to reduce the voltage from the input to the required level. They are ideal for providing stable voltage but are generally inefficient for higher power applications because of the heat generated.
- **Switching Voltage Regulators:** Switching regulators use high-frequency transistors to switch the input voltage on and off rapidly, storing and releasing energy through inductors and capacitors to achieve the desired output voltage. They are more efficient than linear regulators, especially for higher power applications. Switching regulators come in three types: Buck Converters (step-down voltage), Boost Converters (step-up voltage), and Buck-Boost Converters (can step voltage up or down, depending on input and output conditions).

Table 3.1.5: Voltage Regulation Technology Comparison

Specifications	Linear Voltage Regulation	Switching Voltage Regulation		
		Buck	Boost	Buck-Boost
Efficiency	Moderate	High	High	High
Heat Generation	Moderate	Low	Low	Low
Size	Larger	Compact	Compact	Compact
Complexity	Simple	Moderate	Moderate	High
Voltage Ripple	Low	Low	Moderate	Low
Cost	Low	Moderate	Moderate	Moderate

Best Use Case	Step-down	Step-down	Step-up	Step-up and step-down
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3.1.8.1 Linear Voltage Regulators

Linear voltage regulation is one of the simplest and oldest methods of voltage regulation. In a linear regulator, the excess voltage is dissipated as heat, meaning the system must manage heat dissipation with heatsinks or other cooling methods. The efficiency of linear regulators is typically low, because a significant portion of the power is lost as heat. The main advantage of linear regulators is their simplicity and the clean, low-noise output they provide. This makes them ideal for sensitive analog applications, such as audio circuits and analog sensors, where maintaining a stable, noise-free voltage is essential. However, for applications that require high efficiency or deal with higher power levels, linear regulation becomes impractical due to excessive heat generation and the inefficiency of the process.

3.1.8.2 Switching Voltage Regulators

Switching regulators, on the other hand, use a completely different approach. Instead of dissipating excess energy as heat, they work by switching the input voltage on and off at high frequencies and storing the energy in inductors and capacitors. This process allows them to convert a higher input voltage to a lower or higher output voltage with high efficiency. One of the main advantages of switching regulators is their efficiency. Because they do not rely on dissipating excess energy as heat, they generate minimal heat, even when powering high-current devices like the Raspberry Pi or high-power sensors. In fact, switching regulators are able to handle larger power loads without excessive temperature rise, which makes them ideal for powering power-hungry devices. Switching regulators come in several varieties:

- **Buck Converters:** These are used for step-down voltage conversion, where the input voltage is reduced to a lower output voltage. They are highly efficient and are used in applications where the input voltage is higher than the desired output voltage.
- **Boost Converters:** These are used to step up the input voltage to a higher output voltage. They are useful when the input voltage is lower than what is required by the load.
- **Buck-Boost Converters:** These converters can either step up or step down the input voltage depending on the input-output relationship. They are highly versatile and provide flexibility in handling variable input voltages.

Despite their greater complexity, switching regulators are the preferred choice for applications that require high-efficiency power conversion and heat dissipation management. The increased complexity is due to the need for additional components such as inductors, diodes, and capacitors, which help store and filter energy.

3.1.8.3 Voltage Regulation Technology Selection

After evaluating the different voltage regulation technologies, Switching Voltage Regulators (SMPS) are selected as the optimal choice for our project. Switching regulators provide high efficiency (typically 85-95%), low heat dissipation, and the flexibility to handle both step-up (boost) and step-down (buck) voltage conversions,

making them ideal for the varying voltage requirements in our system. The system includes components such as the Raspberry Pi and ultrasonic sensors, which require 5V, and the ESP32, which needs a 3.3V output. Switching regulators will be used to step down the voltage from the 12V power supply to 5V for these components. Additionally, the charger controller needs 12.6V for charging the 3S lithium-ion battery pack, which will be provided by a boost converter. Efficiency is not a critical concern, but in our case, switching regulators provide the necessary performance without the downside of significant power loss and heat dissipation.

3.1.9 PowerPath Controller

A PowerPath Controller is a critical component in power management systems, particularly in applications that involve multiple power sources such as a main power supply and a backup battery system. The primary function of a PowerPath Controller is to regulate the flow of power between the battery and the primary power source, ensuring that the system operates without interruption. The PowerPath Controller determines when to switch between sources based on input voltage availability, allowing the system to always draw power from the optimal source. There are several technologies used in PowerPath controllers, each with varying levels of complexity, efficiency, and functionality. These technologies include diode-based PowerPath control, MOSFET-based PowerPath control, and dedicated PowerPath controller ICs. Each of these technologies offers distinct advantages and limitations that influence their suitability for different applications.

Table 3.1.6: PowerPath Controller Technology Comparison

Specifications	Diode-based PowerPath Control	MOSFET-based PowerPath Control	Dedicated PowerPath Controller ICs
Efficiency	~60% - 80%	~80% - 90%	~80% - 95%
Size	Moderate	Moderate	Compact
Heat Generation	High	Moderate	Low
Response Time	Fast	Fast	Delayed
Complexity	Simple	Moderate	Complex
Control Features	Basic	Advanced	Advanced
Cost	Low	Moderate	High
Best Use Case	Low-power	High-power	High-efficiency

3.1.9.1 Diode-based PowerPath Control

The diode-based PowerPath controller is one of the simplest and most cost-effective solutions. It works by placing diodes between the power source and the load to prevent the

reverse flow of current. While this solution is reliable, it suffers from inefficiency due to the voltage drop across the diodes. This leads to power loss and heat generation, which makes this solution unsuitable for high-power applications. However, for low-power systems, where efficiency is less of a concern, diode-based systems are a cost-effective and straightforward choice.

3.1.9.2 MOSFET-based PowerPath Control

MOSFET-based PowerPath controllers use MOSFETs to handle power switching. Unlike diodes, MOSFETs have a much lower voltage drop, making them far more efficient than diode-based solutions. This technology allows for high current handling, low heat generation, and high efficiency, making it ideal for applications with higher power demands. However, the design of MOSFET-based controllers is more complex, requiring additional components like drivers and control circuits to operate the MOSFETs.

3.1.9.3 Dedicated PowerPath Controller ICs

Dedicated PowerPath Controller ICs integrate the functions of MOSFETs and control circuitry into a single integrated solution. These integrated circuits are specifically designed to manage the flow of power between the primary power source and the battery. The high efficiency and compact size make these controllers the ideal choice for high-power applications where performance and safety are critical. These ICs are capable of providing advanced automatic switching between power sources, ensuring that the system always operates on the best available power while also preventing issues like overcharging and overheating.

3.1.9.4 PowerPath Controller Technology Selection

After comparing the available technologies, dedicated PowerPath controller ICs are the most suitable choice for our system. While diode-based and MOSFET-based controllers provide simpler and more cost-effective solutions, they are insufficient for the level of control and protection required by our system. The selection of dedicated PowerPath controller ICs ensures high efficiency, minimal heat generation, and the ability to seamlessly switch between the primary power source and the backup battery.

3.1.10 Charger Controller

A charger controller plays a crucial role in managing the charging process of battery packs, ensuring the battery is charged efficiently and safely. It regulates both the charging voltage and current, which helps prevent battery damage due to overcharging or overcurrent situations. Proper charging not only ensures the battery's longevity but also contributes to the safety and reliability of the system as a whole. In battery-powered systems, especially those with multi-cell batteries, efficient charging is even more important to ensure each cell is balanced and charged optimally. The most common charging technologies are Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT). Both methods use different approaches to regulate and optimize charging.

3.1.10.1 Pulse Width Modulation (PWM)

PWM charger controllers are the most common and widely used technology for battery charging. They work by regulating the duty cycle of a square wave to control the charging

current supplied to the battery. By adjusting the pulse width, the system ensures that the battery receives the correct voltage and current, which can be maintained for different stages of the charging cycle (constant current, constant voltage). PWM chargers are efficient, relatively inexpensive, and simple to implement. These controllers are ideal for applications where the input power is stable.

3.1.10.2 Maximum Power Point Tracking (MPPT)

MPPT controllers are designed to maximize the energy harvested from solar panels by continuously adjusting the charging parameters to operate at the maximum power point of the panel. MPPT is especially useful in solar applications where the input voltage varies based on light intensity, temperature, and other factors. MPPT controllers offer higher efficiency than PWM controllers because they can extract the most power from a variable input. However, they are typically more complex and expensive than PWM chargers. MPPT is essential when solar power or other variable sources are used to charge the battery, but for our project, where the input voltage is regulated, PWM technology is sufficient and more cost-effective.

3.1.10.3 Charger Controller Technology Selection

After comparing PWM and MPPT charger controllers, we selected PWM technology as the most appropriate solution for our system. The primary reason for this decision is that our system uses a regulated 12.6V input, making the use of MPPT unnecessary. Since PWM controllers are simpler, more cost-effective, and highly efficient for systems with a stable power source, they are the best fit for our needs. Additionally, PWM chargers provide sufficient performance to safely charge our 3S lithium-ion battery pack while keeping system complexity and cost low. The MPPT technology, while more efficient, is better suited for systems where input power varies, such as solar applications, and does not provide a significant advantage in our case.

3.1.11 Batteries

In any energy storage system, selecting the right battery technology is critical to ensure the system's performance, reliability, and safety. For our project, we require a rechargeable battery to provide a sustainable solution for storing energy that can be drawn upon when the primary power source is unavailable or insufficient. Rechargeable batteries are essential because they allow for multiple charge and discharge cycles, ensuring the system can operate effectively over extended periods without the need for constant replacements. Among the many types of rechargeable batteries available, the most common and suitable technologies for our system are Lithium-ion (Li-ion), Lithium Iron Phosphate (LiFePO4), and Nickel Metal Hydride (NiMH) batteries. In this section, we will compare these three battery types based on key features such as energy density, cycle life, safety, and cost, to determine the best choice for our 3S battery pack.

Table 3.1.7: Battery Technology Comparison

Specifications	Li-ion	LiFePO4	NiMH
Energy Density	150-250Wh/kg	90-120Wh/kg	60-120Wh/kg

Nominal Voltage	3.6V per cell	3.2V per cell	1.2V per cell
Cycle Life	500-1000 cycles	1000-2000 cycles	300-500 cycles
Capacity Range	100mAh - 3000mAh+	100mAh - 5000mAh+	1000mAh - 2000mAh
Cost	High	High	Moderate
Best Use Case	High-performance	High safety and longevity	Moderate-power applications

3.1.11.1 Lithium-Ion (Li-ion) Batteries

Lithium-ion (Li-ion) batteries are among the most widely used battery technologies due to their high energy density, efficiency, and long cycle life. With an energy density ranging from 150-250 Wh/kg, they offer significant advantages over other chemistries, such as NiMH, making them ideal for high-demand applications like portable electronics, electric vehicles, and solar-powered systems. With a voltage range of 3.6V to 4.2V per cell, Li-ion batteries are well-suited for applications requiring higher voltage and are capable of delivering longer runtimes and rapid charging. Their cycle life, typically ranging from 500 to 1000 cycles, is relatively long compared to other battery types, though this depends on factors like depth of discharge and charging conditions. However, Li-ion batteries require a Battery Management System (BMS) to ensure safe operation, as they are sensitive to overcharging, overheating, and deep discharge, which can lead to safety risks such as thermal runaway. Despite these challenges, Li-ion batteries remain the preferred choice due to their reliability, compactness, and overall performance in energy-intensive applications. However, they tend to be more expensive than other chemistries due to their advanced design and safety features.

3.1.11.2 Lithium Iron Phosphate (LiFePO₄) Batteries

Lithium Iron Phosphate (LiFePO₄) batteries, a subset of Li-ion technology, provide a safer alternative with higher thermal stability and a significantly longer cycle life compared to traditional Li-ion batteries. While their energy density is lower, LiFePO₄ batteries are known for their robustness and resilience to temperature fluctuations, making them ideal for applications that prioritize safety, reliability, and long lifespan over compactness and power density. With a nominal voltage of 3.2V per cell, they can be easily configured for multi-cell applications, such as energy storage systems, electric vehicles, and solar energy storage. These batteries are much less prone to thermal runaway or overheating, offering low risks of fire and providing high safety margins. Their cycle life often exceeds 2,000 cycles, which reduces the need for frequent replacements and makes them cost-effective in the long term. Though they are larger and heavier than Li-ion batteries, their safety features and long-term reliability make them an excellent choice for high-safety.

3.1.11.3 Nickel Metal Hydride (NiMH) Batteries

Nickel Metal Hydride (NiMH) batteries offer a reliable and environmentally friendly alternative for energy storage systems, with moderate energy density typically around 60-120 Wh/kg. While they are not as energy-dense as Li-ion or LiFePO₄ batteries, they are

still widely used in applications like consumer electronics and low-power energy storage systems. NiMH batteries are known for their robustness and safety, and they perform well in moderate-power applications where cost-effectiveness and environmental considerations are prioritized. However, their higher self-discharge rate makes them less suitable for applications where long-term energy storage is required. Despite this, their reliability and safety make them a practical option for medium-power applications where energy density is not the primary concern.

3.1.11.4 Batteries Technology Selection

After evaluating the different battery technologies, we selected Lithium-ion (Li-ion) batteries for our project due to their high energy density, efficient charging, and long cycle life. Since our system is equipped with a Battery Management System (BMS), we can ensure safe operation, including cell balancing and protection against overcharging, overdischarge, and thermal events. Li-ion batteries offer the best performance for our 3S battery pack with a high energy density, providing longer runtimes and compactness that are critical for our system. They also offer a cycle life of 500-1000 charge cycles, making them suitable for long-term use.

3.1.12 Battery Management System (BMS)

A Battery Management System (BMS) plays a key role in managing and monitoring the health and performance of a battery pack, ensuring safe operation and efficient energy usage. It is responsible for regulating charging, discharging, and battery protection, including features such as voltage balancing, temperature regulation, and current monitoring. In systems that rely on lithium-ion batteries, such as a 3S battery configuration for this project, the BMS ensures that the battery operates within safe voltage limits to prevent overcharging, overdischarging, or overheating, all of which could lead to decreased battery lifespan or even dangerous situations. Beyond safety, the BMS helps maximize battery efficiency by optimizing charge cycles, ensuring that the battery's capacity is used most effectively over its lifespan. The technology behind the BMS can vary depending on the type of battery, its intended application, and the level of sophistication required. In this section, we will compare different BMS technologies and identify the most suitable one for our system's needs. The primary technologies used in BMS solutions include:

- Centralized BMS
- Distributed BMS
- Modular BMS

Table 3.1.8: BMS Technology Comparison

Specifications	Centralized BMS	Distributed BMS	Modular BMS
System Architecture	One central unit	Multiple units communicating	Independent units with main control
Cell Monitoring	Centralized	Distributed by individual unit	Each module monitors its cells
Communication	Single communication	Communication between modules	Communication between modules and main unit
Current Handling	~10-30A	~20-50A	~20-50A
Complexity	Simple	Complex	Complex
Cost	Low	Moderate	High
Best Use Case	Small to medium systems	High-power systems	Large-scale systems

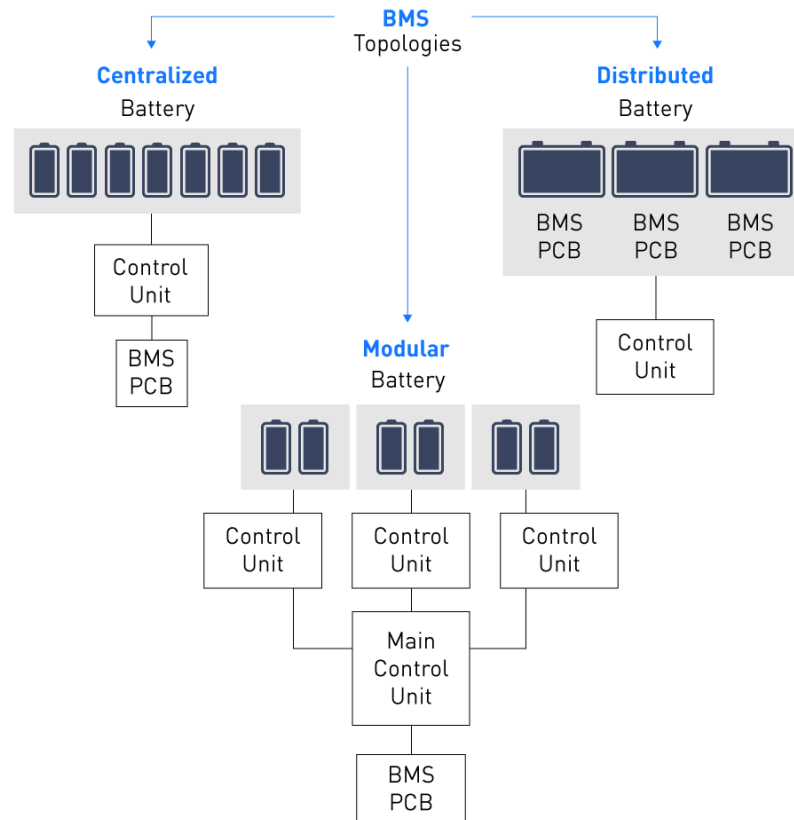


Table 3.4: BMS architectures

3.1.12.1 Centralized BMS

A Centralized Battery Management System uses a single control unit to monitor and manage all the cells in the battery pack. This unit performs critical functions such as voltage and temperature monitoring, cell balancing, and protection against conditions like overvoltage, undervoltage, and overcurrent. The control unit receives direct input from each individual cell, making the system simple to implement, with straightforward wiring and low overall cost. However, this architecture lacks redundancy if the control unit fails, the entire BMS becomes inoperative. Despite this, centralized BMSs are widely used in small to medium-sized systems where cell count is manageable and physical space is limited. In our case, using a fixed 3S lithium-ion battery pack, a centralized BMS provides all necessary protections and monitoring capabilities without adding unnecessary complexity or cost.

3.1.12.2 Distributed BMS

In a Distributed BMS, the system utilizes multiple BMS PCBs, each responsible for monitoring and managing groups of cells or individual cells. These distributed units communicate with a control unit. The central control unit aggregates the data from each of these distributed BMS PCBs to ensure the battery pack operates efficiently and safely. The Distributed BMS design offers several advantages, primarily in terms of redundancy and scalability. Since each BMS PCB is independently responsible for a group of cells, the failure of one PCB does not compromise the entire system. This type of BMS is ideal for high-power applications like electric vehicles, energy storage systems, and industrial applications, where larger battery packs and higher currents are involved. However, for a compact embedded systems like ours, though, they would add unnecessary complexity and expense.

3.1.12.3 Modular BMS

A Modular Battery Management System builds on the concept of a distributed BMS but takes it a step further by using fully autonomous modules, each responsible for managing its own battery pack. Each module includes its own control unit, along with integrated monitoring, balancing, and protection circuitry, and communicates with a main control unit that coordinates the entire system. This architecture provides maximum flexibility and scalability, as modules can be easily added or replaced without affecting the rest of the system. The Modular BMS also improves fault isolation and allows for simplified maintenance, as a failure in one module won't compromise the rest of the system. However, the trade-off comes in the form of higher cost, increased complexity, and more sophisticated communication and integration requirements. Modular BMSs are typically used for large-scale industrial or grid-tied energy storage systems. For our project, which features a single, compact 3S pack with relatively modest current demands, a modular BMS would be excessive and unnecessarily complex.

3.1.12.4 BMS Technology Selection

After evaluating the main BMS architectures—centralized, distributed, and modular—we selected the Centralized BMS architecture as the most appropriate for our project. Our system uses a fixed 3S lithium-ion battery pack, which does not require the scalability or redundancy offered by more complex architectures. A centralized BMS provides all the

essential features, including cell voltage monitoring, balancing, and protection against overvoltage, undervoltage, overcurrent, and short-circuit conditions, while keeping the design simple and cost-effective. Compared to distributed or modular systems, a centralized BMS is easier to implement, more affordable, and well-suited for compact embedded applications like ours. Since our project does not demand multi-module coordination or node-level fault tolerance, the centralized approach offers the best combination of safety, reliability, and ease of integration for our battery management needs.

3.2 Part Selection

3.2.1 Microprocessors Selection

Microcontrollers and single-board computers play a crucial role in processing and handling data for embedded systems. In the context of the License Plate Recognition (LPR) system, selecting the appropriate processing unit is vital to ensure smooth real-time image recognition, energy efficiency, and seamless integration with peripherals. The ideal choice should provide adequate computational power to handle image processing tasks while maintaining compatibility with necessary software libraries and hardware modules. Factors such as power consumption, availability, community support, and cost must also be considered.

3.2.1.1 Raspberry Pi 4

One of the most commonly used options for embedded systems is the Raspberry Pi 4, which offers a balance of processing power, affordability, and a well-established ecosystem of support. Equipped with a quad-core ARM Cortex-A72 processor running at 1.5GHz, the Raspberry Pi 4 provides sufficient computational resources to execute real-time image processing tasks efficiently. It supports multiple camera interfaces, including the MIPI CSI connector, allowing for easy integration with high-resolution camera modules required for LPR applications. The Raspberry Pi 4 also has extensive documentation and community support, making it a highly accessible platform for development. However, one drawback is its relatively high-power consumption compared to traditional microcontrollers, which could be a concern in battery-operated setups.

3.2.1.2 NVIDIA Jetson Nano

Another potential candidate is the NVIDIA Jetson Nano, a single-board computer designed specifically for artificial intelligence and machine learning applications. It features a quad-core ARM Cortex-A57 processor alongside a 128-core Maxwell GPU, making it exceptionally well-suited for computer vision and deep learning tasks. The Jetson Nano provides native support for AI frameworks such as TensorFlow, PyTorch, and OpenCV, which are crucial for optimizing LPR software. Despite its powerful computational capabilities, the Jetson Nano is more expensive than the Raspberry Pi 4 and requires a higher power input, making it less practical for power-sensitive applications. Its complexity in setup and configuration could also be a limiting factor for this project.

3.2.1.3 Google Coral Dev Board

The Google Coral Dev Board is another viable option for LPR applications, specifically designed for edge AI and machine learning tasks. It features an NXP i.MX 8M SoC along with a Google Edge TPU (Tensor Processing Unit), which significantly accelerates deep learning inference tasks. The board is optimized for TensorFlow Lite models and can efficiently process image recognition algorithms in real time. With a dedicated TPU, it offers low power consumption while maintaining high processing speeds. However, the Coral Dev Board is less commonly used compared to the Raspberry Pi and Jetson Nano, which could result in fewer available resources and community support.

3.2.1.4 BeagleBone AI-64

The BeagleBone AI-64 is an advanced option for embedded AI applications, offering a Texas Instruments TDA4VM SoC with integrated deep learning acceleration. It provides a robust computational platform with support for OpenCL and deep learning frameworks, making it well-suited for LPR tasks. The board includes multiple camera interfaces and supports real-time video processing. Its main advantages include industrial-grade reliability and extensive expansion capabilities. However, the BeagleBone AI-64 is relatively expensive and requires more technical expertise to configure compared to the Raspberry Pi.

3.2.1.5 Final Selection

After a thorough evaluation, the Raspberry Pi 4 was selected as the optimal choice for the LPR system. It provides a good balance between performance, affordability, and ease of integration. Its strong software ecosystem, compatibility with OpenCV, and availability of official camera modules make it a practical solution for implementing real-time license plate recognition. The Raspberry Pi 4's relatively low cost compared to the Jetson Nano, coupled with its widespread community support, ensures that potential technical challenges can be resolved efficiently. Although it has higher power consumption than microcontrollers, this trade-off is acceptable given its advantages in image processing and ease of implementation. Therefore, the Raspberry Pi 4 will serve as the primary processing unit for the LPR subsystem in the Parking Garage Management System.

Table 3.2.1: Microprocessor Comparison

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

3.2.2 Camera Module Selection

Selecting the appropriate camera module is essential for ensuring accurate and reliable license plate recognition. The camera must be capable of capturing high-quality images in various lighting conditions, integrating seamlessly with the selected processing unit, and operating efficiently within the constraints of the parking garage environment. Key factors to consider include resolution, frame rate, low-light performance, interface compatibility, and cost.

3.2.2.1 Raspberry Pi Camera Module V2

The Raspberry Pi Camera Module V2 is a compact and cost-effective solution designed specifically for integration with Raspberry Pi boards. It features an 8-megapixel Sony IMX219 sensor, offering a resolution of 3280x2464 pixels. The camera connects via the MIPI CSI-2 interface, ensuring high-speed data transfer and low latency. It supports video recording at 1080p30, 720p60, and 640x480p90, making it a versatile choice for real-time image processing. One limitation of this module is its suboptimal performance in low-light conditions, which may affect license plate recognition accuracy at night. However, its affordability, ease of integration, and strong community support make it a viable option for the LPR system.

3.2.2.2 Arducam IMX477 (B0240) High-Resolution Camera

The Arducam IMX477 is a high-resolution camera module designed for advanced imaging applications. It features a 12.3-megapixel Sony IMX477 sensor, delivering a resolution of 4056x3040 pixels. This camera supports higher frame rates and improved low-light performance compared to the Raspberry Pi Camera Module V2. It also includes manual exposure and gain controls, allowing for better adaptability in varying lighting conditions. While the IMX477 provides superior image quality, it is more expensive and requires additional components, such as a compatible lens, increasing the overall cost.

3.2.2.3 ELP USB 1080p Low-Light Camera

The ELP USB 1080p Low-Light Camera is a third-party USB camera designed for high-performance imaging in low-light environments. It features a 2-megapixel sensor with a resolution of 1920x1080 pixels. Unlike MIPI CSI-based cameras, this module connects via USB, making it compatible with a wide range of processing units, including Raspberry Pi and Jetson Nano. It includes built-in infrared (IR) support, enabling effective nighttime

license plate recognition. However, the reliance on USB connectivity can introduce latency compared to direct MIPI CSI connections.

3.2.2.4 Axis P1445-LE IP Camera

The Axis P1445-LE is a professional-grade IP camera designed for high-resolution surveillance and ALPR (Automatic License Plate Recognition) applications. It features a 5MP sensor with a resolution of 2592×1944 pixels, ensuring clear plate visibility even in challenging conditions. The camera includes integrated infrared (IR) illumination, allowing for effective nighttime operation, which is crucial for parking garage monitoring. It connects via Ethernet and supports Power over Ethernet (PoE) for simplified installation. The Axis P1445-LE also includes edge processing capabilities, meaning it can perform basic image analysis without relying on external hardware. However, its high cost may be a limiting factor for budget-conscious projects.

3.2.2.5 OpenCV AI Kit (OAK-D)

The OpenCV AI Kit (OAK-D) is a cutting-edge camera system designed specifically for AI-powered computer vision applications. It features three cameras: a high-resolution RGB camera and two stereo depth cameras for 3D perception. The OAK-D integrates directly with OpenCV and supports real-time deep learning inference, making it an ideal choice for LPR applications. It is equipped with an Intel Myriad X VPU (Vision Processing Unit), which accelerates neural network computations directly on the camera, reducing the load on the primary processing unit. This module offers excellent low-light performance, integrated depth sensing, and edge AI capabilities. However, it is more expensive than other camera options and requires additional setup and software integration.

3.2.2.6 Camera Module Final Selection

After evaluating the available camera modules, the Raspberry Pi Camera Module V2 was selected as the primary camera for the LPR system. It provides a strong balance of affordability, ease of integration, and compatibility with the Raspberry Pi 4. While its low-light performance is not as strong as other options, additional infrared lighting solutions can be implemented to enhance nighttime detection. The Arducam IMX477 remains a viable alternative if higher resolution and better image quality are required, but its cost and complexity make it less attractive for the initial design. If low-light performance becomes a critical issue, the ELP USB 1080p Low-Light Camera may be considered for future improvements.

Table 3.2.2: 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

3.2.3 License Plate Recognition (LPR) Software

License Plate Recognition (LPR) software is a critical tool used for the detection and identifying of a vehicle license plate and converting it into text all in real-time. The software must be capable of handling different environmental conditions, from varying light conditions to motion blur, and different viewing camera angles. In addition to being highly accurate, the ideal license plate recognition software should also have fast processing, and compatibility with the chosen hardware. There are many LPR software solutions available to choose from, each offering different levels of accuracy, processing speeds and cost. This section explores commercial LPR solutions, followed by a custom implementation approach, dividing the process into two key components: license plate detection **and** optical character recognition (OCR).

3.2.3.1 Commercial LPR Solutions

3.2.3.1.1 OpenALPR

The first option that we considered to be our license plate reader was OpenALPR. OpenALPR is software used to recognize license plates number, also known as Automatic license plate recognition (ALPR). The OpenALPR library as first released in 2015 was written in C++ making use of the OpenCV and Tesseract OCR libraries. Originally built as an open-source free to use initiative, it operates now as a commercial Software-as-a-Service under the ownership of REKOR Recognition Systems requiring a subscription to use. The Technology behind OpenALPR is that it can process both images and videos extracting a vehicles license plate number and other characteristics like make, model and color.

While OpenALPR is known for its high accuracy and consistency in recognizing plate numbers in various conditions, the cost of using it can be a significant drawback. To access

the service, users must subscribe to one of the plans provided starting at a cost of \$10 minimum per month for a very limited service or \$65 for the full feature plan. And that is only for one camera, so using 2 cameras, as our design requires one camera for the entrance and one camera for the exit, will double the budget required to use OpenALPR. On top of that the software requires the installation of an IP camera, which adds to the overall cost as IP cameras are more expensive, and we have already decided not to use them in our design.

3.2.3.1.2 Plate Recognizer

Another license plate recognition software option that we considered using in our project is “Plate Recognizer”. Just like OpenALPR, Plate Recognizer is a commercial License plate Recognition solution designed to provide users with highly accurate recognitions across various conditions and environments. One of its main advantages is its ability to provide accurate results on fast-moving vehicles, and in low-light environments. Another advantage that Plate Recognizer has is its ability to be used with different types of cameras without restricting service to only IP cameras.

Using Plate Recognizer comes with a free trial that gives users up to 2500 monthly lookups at no additional cost. For more monthly lookups that will require a paid subscription ranging between \$50 and \$250. However, even though it is a highly reliable and compatible service with a free trail, it is still a paid software that requires a subscription to be used. The cost factor makes it less suitable for budget sensitive projects or small-scale implementations that require a more affordable alternative.

Table 3.2.3: Commercial LPR Solution Comparison

Feature	OpenALPR	Plate Recognizer
Cloud-based option	Yes	Yes
On-Premises Option	Yes	Yes
Low light performance	Moderate	Strong
Angles plates	Fails at 60 degrees	Accurate up to 60 degrees
Focus area	Law enforcement, surveillance	Parking management, tolling, security
Hardware dependency	Requires specialized hardware	Works with any camera

3.2.3.2 Custom LPR Implementation

For greater control and flexibility, a custom LPR implementation can be developed using separate license plate detection and OCR models. This approach allows for fine-tuning to improve accuracy and adaptability to specific deployment conditions.

3.2.3.2.1 License Plate Detection Models

Custom plate detection involves using deep learning-based object detection models trained on datasets of vehicle license plates. The following models are commonly used for detecting plates in images:

3.2.3.2.1.1 YOLO (You Only Look Once)

YOLO (You Only Look Once): YOLO is a single-stage object detection algorithm designed to be processed in real time. YOLO uses convolutional neural network (CNN) to process the entire image at once instead of scanning different regions individually. The input image will be passed through a series of convolution layers which by the end of it will extract the objects' locations with a high-level understanding of the type of such objects. Once the CNN extracts the features from the image, now YOLO can start processing each object. The first step of a YOLO prediction starts by splitting the image (A) into an $N \times N$ grid with equally sized squares. The next step is to determine and highlight the bounding boxes that contain all the objects within the given image, this process is known as bounding box regression. After the bounding box regression, each detected object will be assigned to one of the grid cells based on where (which box) the center of the object falls into. That one cell will be the only cell responsible for the prediction even if the object spans multiple grid cells. Now that the grid is divided, for each bounding box YOLO will predict: coordinates, an object score (how likely an object is in the box), and class probabilities (what type of object it might be). Since multiple grid cells may predict the same object, a Non-Maximum Suppression (NMS) is applied to only keep the bounding box with highest confidence score. After NMS, YOLO will give back the original image with bounding boxes drawn around the detected objects, with each box containing the following: object name, bounding box coordinates, and confidence score.

Due to it being computationally efficient and fast, YOLO makes a perfect candidate to run on edge devices like the Raspberry Pi or Jetson Nano. But what it gains in speed and efficiency, it loses in detection accuracy particularly when trying to detect small objects or objects in crowded scenes. Later versions like the YOLOv8 addressed these issues and improved model accuracy. Despite its accuracy limitation, compared to 2 stage detectors, YOLO remains one of the most widely adopted LPR algorithms due to its balance of speed and accuracy.

3.2.3.2.1.2 Faster R-CNN

Faster R-CNN is a two-stage object detection model that consists of two main components: a Region Proposal Network (RPN) and a Fast R-CNN detector. The first step in Faster R-CNN is to identify the Regions of Interest where the objects are likely to be present within the image. To identify such Regions of Interest, Faster R-CNN utilizes a Region Proposal Network which is a Convolutional Neural Network. The input image is passed through the CNN network, producing on the other end an output image with boxes overlaid on top of it identifying a list of protentional object locations.

Once the Region Proposal Network suggests the object locations within the image, the second stage of the R-CNN extracts these regions and passes them through a fully

connected neural network layer. The result is a more refined bounding box region with a class label and a confidence score.

Unlike YOLO, which is a single stage detector that processes an image in a single pass, Faster R-CNN processes an image in two stages enabling higher precision and accuracy in detecting and classifying an object. But the higher accuracy of a two-stage detector comes at the cost of a slower inference speed and higher computational intensity. This computational intensity of Faster R-CNN requires high end GPUs for real time processing making it less suitable for embedded systems. Overall, Faster R-CNN is best suited for LPR detection where accuracy is more critical than speed.

3.2.3.2.1.3 SSD

SSD (Single Shot MultiBox Detector): is a single-stage object detection algorithm that is designed to be fast and accurate object detection. It was originally introduced as an alternative for Faster R-CNN, which while it is accurate, is too slow for applications that require real time processing. SSD was introduced as an object detection that balances speed and accuracy, making it a popular choice for real-time applications like license plate recognition and autonomous driving.

The SSD process begins with what is known as a base network which is a pre-trained convolution neural network. The base network takes the image as an input, passes it through the convolution layers and generates a feature map that is essential for object detection. Once the image enters the base network, each additional layer that it passes through gets progressively smaller which makes it capable of detecting objects at different scales.

SSD uses a technique known by default boxes (anchor boxes) at each of the locations in the feature maps. Each of these boxes comes in various sizes and are assigned to every cell in the feature map. After these boxes are assigned, class scores are then assigned to each one of them acting as the object prediction. One of SSDs' strength is its ability to detect objects of various sizes which make it robust in varying conditions. This model achieves good performance while also requiring fewer computational resources compared to Faster R-CNN, making it an excellent choice for LPR applications.

3.2.3.2.1.4 LPR Model Selection

After comparing and evaluating various license plate detection models, the most suitable choice for this project is YOLO. YOLO was selected due to its balance between real-time processing capabilities, accuracy and computational efficiency. Unlike Faster R-CNN which requires development boards with higher end GPU, YOLO on the other hand processes an image in one pass making it significantly faster and more efficient. This one key advantage of being computationally efficient, makes YOLO a perfect choice to be run on edge devices like the Raspberry Pi. This balance of speed, efficiency and accuracy, makes YOLO an optimal model for detecting license plates.

Table 3.2.4: LPR Model Selection Comparison

Feature	YOLO	Faster R-CNN	SSD
Detection Type	Single-stage	Two-stage	Single-stage
speed	Very fast (real-time)	Slower (not real-time)	Fast (balances speed and accuracy)
Accuracy	Moderate (lower for small objects)	High (best for precision tasks)	Higher than YOLO, lower than Faster R-CNN
Computational requirements	Low	High	Moderate
Handling of small objects	Weak	Strong	Moderate
Suitability for Embedded Systems	Yes	No	Partially

3.2.3.2.2 Optical Character Recognition (OCR) Models

Once the license plate has been detected, OCR is required to extract the alphanumeric characters. The following OCR models are widely used for license plate recognition:

3.2.3.2.2.1 Tesseract OCR

Tesseract OCR: Tesseract is an open-source Optical Character Recognition (OCR) developed by google. The Tesseract engine was originally developed by Hewlett-Packard as a proprietary software, but since 2006 google has been sponsoring the development of Tesseract and released it as a free to use open-source OCR engine. Tesseract is widely used text recognition software, constantly ranking in the top 3 of the most used OCR engines. Tesseract weakness comes from its need to be fed preprocessed images that are scaled to at least 20 pixels, rotations and skews must be correct, low-frequency changes in brightness must be high-pass filtered, and dark edges must also be completely removed, or they will be misread as characters. If Tesseract input image as not preprocessed, then the output will be of a very low quality. This requirement for preprocessing makes it difficult to be used for LPR applications where we constantly have changes in angles, light and scaling.

3.2.3.2.2.2 EasyOCR

EasyOCR: EasyOCR is an OCR model that uses deep learning neural networks, like Convolutional Neural Networks, to recognize texts in images. The use of a deep learning neural network gives EasyOCR a higher performance and accuracy on noisy, distorted and angled images compared to traditional OCR models like Tesseract OCR. When trained on custom datasets, EasyOCR can be a perfect choice especially for License Plate Recognition software.

During the optical character recognition, a bounding box with X and Y coordinated are displayed in the image where text is located. After the Text location is identifies, a text translation happens accompanied with a confidence score. A major difference between

EasyOCR and Tesseract, is that EasyOCR can work directly with BGR images within OpenCV, while tesseract requires a conversion of the RGB prior to proceeding further.

3.2.3.2.2.3 PaddleOCR

PaddleOCR: PaddleOCR is a state-of-the-art deep learning OCR framework that provides high accuracy and real-time processing capabilities. It supports various text orientations and performs well on real-world license plates. PaddleOCR is particularly effective for applications requiring multi-region license plate recognition.

PadddleOCR is an OCR framework that is built on a deep-learning Convolutional Neural Network (CNN), providing high accuracy and real-time processing capabilities, making it a suitable and strong candidate for license plate recognition applications. PaddleOCR was developed PaddlePaddle deep learning platform and was optimized for detecting and recognizing text in multiple languages and varied text orientations. One of the key strengths of the PaddleOCR engine is its utilization of a two-stage detection approach, where it first detects the regions in the image that have text in them and then applies the recognition engine to convert them into text. Additionally, PaddleOCR incorporates lightweight models making it suitable for low power edge devices like the Raspberry Pi.

3.2.2.2.5 Final OCR Selection

Selecting the right Optical Character Recognition (OCR) model depended on several desired features, including accuracy, speed, and computational efficiency. Based on our requirement for an ALPR system that processes license plates in real time accurately and efficiently, PaddleOCR is chosen as the optimal choice. PaddleOCR outperforms Tesseract and EasyOCR in accuracy, speed and robustness, making it the best option for real time license plate recognition especially with varying environmental conditions.

Table 3.2.5: OCR Models Comparison

Feature	Tesseract	PaddleOCR	EasyOCR
OCR type	Traditional OCR	Deep Learning-Based	Deep Learning-Based
Processing speed	Slow (depends on preprocessing)	Fast (optimized for real-time)	Moderate
Accuracy	Moderate (struggles with distorted text)	High (performs well on LPR)	Good (better than Tesseract, lower than PaddleOCR)
Handling of Noisy/Blurred Images	Weak (requires extensive preprocessing)	Strong (handles blurry and tilted text)	Moderate (performs well but not as robust as PaddleOCR)
support for Multiple Languages	yes	yes	yes
Edge Device Compatibility	yes	yes	yes

Ease of Integration	Easy	Moderate (requires setup but well-documented)	Easy
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3.2.4 Ultrasonic Sensors

Since we will be using ultrasonic sensors for car detection in the parking spot, we will need to find sensors that will have all the features that we need, while not being too overly complicated. We will also be focusing on low-cost sensors as one of our priorities for using ultrasonic sensors is to reduce cost, so if we chose an expensive ultrasonic sensor, it takes away the reduced cost aspect from the benefits of using an ultrasonic sensor. Our ultrasonic sensor that we pick should also be able to detect at least from the height of a typical indoor parking garage.

3.2.4.1 SparkFun Electronics HC-SR04

One of our first picks for an ultrasonic sensor is the HC-SR04 Ultrasonic Sensor by SparkFun Electronics. This ultrasonic sensor is a popular low-cost ultrasonic sensor that includes an ultrasonic transmitter, receiver, and a control circuit. It can measure distances from as small as 2 centimeters to as big as 4 meters with about a 3mm accuracy range, which is very good considering the cost. The trigger pin sends out the ultrasonic soundwave and the echo pin is where it receives the time it took for the soundwave to bounce back, which allows the user to also calculate the distance that the soundwave traveled. This also means that the output for the HC-SR04 is digital, which can affect usage depending on what readings we will need from it. This sensor is not too small or too large, boasting a size of 43mm long, 20mm wide, and a height of 15mm. Since it is so popular and cheap (~\$4), we want to pick it due to the amount of information that can be found online about it by other people who have used it.

3.2.4.2 MaxBotix MB7360

Another ultrasonic sensor that we were looking at was the MaxBotix MB7360 High Precision Ultrasonic Sensor. It is designed for outdoor environments and has weather-resistant housing, which would be good for a parking lot that might implement our system. It can sense from 30 cm to 5 meters, which has a maximum range that is a bit further than the HC-SR04 but also has a smaller minimum range than the HC-SR04. It has multiple output options like analog voltage, pulse-width modulation (PWM), and serial, which allows it to be very versatile on how we want to use it. This sensor has a diameter of 44 mm and a height of 70 mm, so it isn't that small compared to the HC-SR04 sensor. This sensor is industrial grade, so it is not meant for hobby uses as arduino compatibility is a bit more complicated, but it also means the durability is a lot better than the lower cost options, but it is a lot more expensive (~\$110).

3.2.4.3 MaxBotix MB1014

Another ultrasonic sensor that we were looking at was the MaxBotix MB1014 Long Range Ultrasonic Sensor. This ultrasonic sensor was designed to be used for applications where it would be necessary for the ultrasonic sensor to detect longer ranges compared to the other two ultrasonic sensors I talked about. It can provide precise measurements from 15cm all the way to 6.45 meters, which is the furthest of all the ultrasonic sensors we have

compared. It also has the same output options of the MB7360 sensor, which are analog voltage, PWM, and serial. Compared to the MB7360 sensor, this sensor is not industrial grade and is meant for use not only by companies but people who want to use the sensor with an arduino can also do that. This sensor is about 19.9 mm wide, 22.1 mm long, and 15.5 mm tall, about half of the HC-SR04 sensor. The cost of this sensor (~\$30) is a lot less than the MB7360 sensor, but it still does not come close to the very cheap HC-SR04 sensor.

3.2.4.4 Which Ultrasonic Sensor?

The ultrasonic sensor that we decided to go with is the SparkFun HC-SR04. Due to the low cost of the sensor and our previous experience with that sensor, we decided on using it. The accuracy that we have tested before is more than adequate enough for our use case. Our project will emulate a small parking garage, so the long range of the MaxBotix MB1014 is not needed. The MaxBotix MB7360 is not only overkill for our project, but also way too expensive and the more complicated compatibility due to the industrial aspect of the sensor is enough to turn us to the HC-SR04 sensor.

Table 3.2.6: Ultrasonic Sensors Comparison

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

3.2.5 MCU

Since we need an MCU to handle our real time processes, there are also some requirements that we need to take a look at. Since we will include multiple ultrasonic sensors, LEDs, and a display to show the number of cars in the parking garage, we will need an MCU that has a lot of GPIO pins to ensure we will have enough pins for those components. For communication to the database, we will also need wireless functionality, specifically Wi-Fi since we will be using it to handle the transmissions between the camera and the database.

3.2.5.1 ESP32

The ESP32 is a microcontroller that has all of the features that we need to implement it as our main MCU for our project. It has either a single or dual core processor, wireless connectivity, multiple pins to use for interfacing, and more ADC channels. One of the main points of it was that it had Wi-Fi and Bluetooth connectivity, allowing it to connect to our database that records the garage's parking availability. For the ESP32 MCU, there are multiple different variations that you can purchase, like ones with more ram or more GPIO pins. They are all relatively similar, but we did want to choose a model that has more than enough GPIO pins, Wi-Fi capability, and enough performance to handle multiple devices connected to it. We also looked for MCUs that don't use that much power since we are implementing a battery monitoring system (BMS), which could act as a backup system if the electricity ever went out in that garage. For our purposes, the ESP32-S3 meets our requirements for our project and has more GPIO pins than the other models, making it more convenient due to us having multiple sensors/LEDs.

Table 3.2.7: ESP32 Models Comparison

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
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Advantages:

- More processing power with dual core CPU
- More RAM (512 KB)
- Has both Wi-Fi and Bluetooth
- More GPIO pins for more interfacing with components
- More ADC channels

Disadvantages:

- More complex to program
- Higher cost (than ESP8266)
- Uses more power than ESP8266

3.2.5.2 ESP8266

Another MCU we looked at for our project was the ESP8266. It is a single core microcontroller that has Wi-Fi and uses less power than the ESP32. This can be a good option if we were only using one ultrasonic sensor since it seems more than adequate enough, but we are worried that the performance would not be enough for multiple sensors and devices connected to it. It also should theoretically cost less than the ESP32 as it is an older MCU but research shows that you can get an ESP32-S3 module for cheaper than the ESP8266. We decided to not use this since it was not actually cheaper than the ESP32, while having less performance (less cores and less RAM) and no Bluetooth connectivity. This product is considered obsolete as the ESP32 is designed to replace the ESP8266 since most of the features are already on the ESP32.

Advantages:

- Less power usage
- Easier to use since it is simpler

Disadvantages:

- Less RAM
- No Bluetooth
- Less GPIO pins
- Worse performance than ESP32
- Not Cheaper than ESP32
- Older and Obsolete

3.2.5.3 RP2040

One of the other microcontrollers that we looked at was the RP2040 microcontroller from Raspberry Pi. It is a low power, dual-core microcontroller that focuses on affordability and ease of use, especially with the USB support with their USB controller integrated onto the chip. This could allow for easier device handling but for our project, there is no need for USB devices. One of the reasons we look at this is that for the MPU, we were looking at

the Raspberry Pi devices to handle our machine learning task with the camera. The reason why we have decided not to use this MCU is due to the lack of Wi-Fi capabilities, as well as the performance not being up as good as the ESP32.

Advantages:

- Dual core processing
- Cheaper than ESP32 and ESP8266
- More documentation and support with the Raspberry Pi community
- USB controller built on

Disadvantages:

- No Wi-Fi or Bluetooth
- Less GPIO pins
- Worse performance than ESP32
- Deep sleep power consumption is higher than ESP32

3.2.5.4 Which MCU?

The microcontroller that we decided on choosing was the ESP32-S3. One of the main selling points of that MCU was the greater number of GPIO pins, having a dual-core processor for better performance, and Wi-Fi and Bluetooth functionality built into the chip. The ESP8266 microcontroller would have been a good option if not for the fact that the ESP32 was already designed to replace it and that the number of GPIO pins is less than the ESP32-S3 microcontroller. For the RP2040 microcontroller, that was immediately not an option since it does not have Wi-Fi or Bluetooth capabilities on the chip, as well as a lot less GPIO pins as well.

Table 3.2.8: MCU Comparison

Features	ESP32-S3	ESP8266	RP2040
Cores	Dual-Core	Single-Core	Dual-Core
Clock Speed	Up to 240 MHz	Up to 160 MHz	Up to 200 MHz
Wi-Fi	YES	YES	NO
Bluetooth	YES	NO	NO
SRAM	512 KB	64 KB	264 KB

Average Power Consumption (mA)	120 mA	70.5 mA	24 mA
GPIO Pins	45	33	30
Cost	~\$3-\$5	~\$7	~\$1

3.2.6 Display

For the display that shows the number of free parking spaces, we will go with LED screens for the final product since it will be brighter and require less maintenance. There were a couple displays that we were looking at, including a 7-segment LED display that can be enough for our intended purpose. As long as a display was bright enough, not too expensive, and hopefully has low power consumption, it would be one of the top choices for our displays.

3.2.6.1 TM1637

The TM1637 LED display is a 7-segment display that has low power consumption and high brightness for viewing during the day. It is a simple display that can only show numbers, but that is fine for our use case. The brightness on this display is good, but outdoor visibility of this display can be a bit worse than others, especially due to the size of it. This display is very cheap, you are able to find them for around \$5 if not less. Their display has one of the lower average power consumptions, consuming on average about 25 mW, which is great for our project as that means it will sip on power when on the battery backup system. TM1637 displays are typically used in clock and counter applications, so they exceed there but might not be enough for our use case due to the fact that the display is so small.

Advantages:

- Lowest cost
- Low power consumption
- Simple to use

Disadvantages:

- Limited to numbers (Not too much of an issue in our case)
- Not that visible in bright light situations
- A little smaller than we need

3.2.6.2 MAX7219

The MAX7219 Matrix LED display is a 8x8 matrix display that can be combined to create a larger display itself. They are regularly sold as 1 panel or in a group of 4 panels in a single module so that you can have more space to display whatever text or numbers you want. The LEDs in the matrix are not that bright compared to the TM1637 LED display, but they are able to be scaled up with more of the 8x8 matrix displays so that it can display bigger

messages, making visibility better than just having one of the TM1637 displays. This display has pretty low average power consumption, about 15.4 mW, which is even lower than the TM1637 display. The cost of the MAX7219 LED displays is almost the same as the TM1637 display, just a few dollars more on average depending on the certain one you get, like just 1 or 4 panels.

Advantages:

- Low cost
- Lowest power consumption
- Simple to use
- Can display text or symbols
- Can be scaled up to be a bigger size if needed

Disadvantages:

- Not that bright
- Can be harder to see than TM1637

3.2.6.3 P10 LED Display

Being one of the larger displays of our choices, the P10 LED Display module is kind of perfect for our use case when used in a full-scale parking garage. It is big enough and bright enough for drivers to see it far away, allowing better ease of use for the customer with this display. This kind of display is greatest for large visible signs, which is what we need. The power consumption on this display is quite a bit more than the last two displays, consuming about 8 to 10 watts on average. Another problem is that the cost of these displays can start from about \$20 but can go up to a lot more if you need a full color display or a bigger version.

Advantages:

- Large enough for a parking garage
- Very bright
- Good visibility during the day

Disadvantages:

- More expensive
- Draws a lot more power

3.2.6.3 Which Display?

Since both the MAX7219 display and P10 LED display can be bigger than the TM1637 display, those two displays will be the main ones we will focus on. The MAX7219 display can be as big as the P10 LED display if we get a lot of those panels all wired together, but the P10 display would be better for ease of use and its brightness is a lot higher than the MAX7219. The two downsides of the P10 LED display for our project is that it is expensive and draws a lot more power, but that might not be too big of a deal as the price of the P10 LED display may be about 5 times the price of the other displays, but they were cheap to begin with. As for the greater power consumption, the main power source of our project

will not be the batteries, but from the outlet itself. Thus, making the P10 LED display is our choice for displaying the number of free parking spots in the garage.

Table 3.2.9: LED Display Comparison

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

3.2.7 LEDs

For the LEDs, we decided on using SMD LEDs as they can provide a much brighter light than the DIP LEDs, which we will still use for prototyping. For the LEDs, we want them to be as bright as it can be without costing too much and SMD LEDs do not typically use that much power anyways, so power consumption between them will not be too big of a deal. One of the features we hope to have with our SMD LEDs is that it can output more than one color, making it less necessary to buy two different LEDs to have the green and red indicator.

3.2.7.1 APTBD3216SURKCGKC-01

The APTBD3216SURKCGKC-01 LED is a SMD LED that is made by Kingbright and has a package size of 1206, which should fit the size requirement from the professors. It has two LED diodes in the housing, one red and one green. The brightness of it is good, 250 millicandela for green and 600 millicandela for red, but it does not compare to having one LED with single color diodes. The price of these can be found at similar prices to LEDs that have only one color, so technically it would be cheaper than just buying two LEDs for red or green indication. Since this LED has two diodes in the housing, the soldering points are split off into two so that it can separate the wiring for the red and green LED diodes. This means it is more complicated to solder than the single diode LEDs as the soldering points are a little smaller.

Advantages:

- Red and Green LED diode in one housing
- Can be about the same price as single diode LEDs
- Cheap

Disadvantages:

- Not as bright as single color diodes
- A little more complicated to solder

3.2.7.2 VFR1105W-6C9-TR

The VFR1105W-6C9-TR LED by Stanley Electric Co. is a SMD LED that has a package size of 1206 and one red LED diode. The LED has a millicandela rating of 975 mcd, which is a lot brighter compared to the previous LED discussed. The price is also cheaper than the previous LED, but it emits red so we would have to buy another LED for the green light indication. This LED is easier to solder than the previous LED since it is a normal SMD LED, meaning there are just two soldering points for the cathode and anode.

Advantages:

- Bright
- Pretty cheap

Disadvantages:

- Only red light illumination

3.2.7.3 APTL3216ZGCK-01

For the green LED to pair with the previous APTL3216ZGCK-01 LED by Kingbright, we chose this option. It is another 1206 package size LED with a millicandela rating of 1000 mcd, so it is close to the red LED we would be pairing it with. The cost of this is cheap, but it is the same price as the LED with red and green lights. This LED is a typical SMD LED with two soldering points for the anode and cathode, so it is easier to solder than the first LED.

Advantages:

- Bright
- Cheap
- Easy to solder

Disadvantages:

- Only green light illumination
- Same price as the first LED we talked about with red and green lights

3.2.7.4 Which LED Indicator?

Since the main focus was to find an LED indicator that is bright enough for us to easily spot a free parking spot, we decided to go with the last two LEDs, the VFR1105W-6C9-TR LED for the red-light indication and the APTL3216ZGCK-01 LED for the green light indication. These two LEDs have similar millicandela ratings and are both brighter than the APTBD3216SURKCGKC-01 LED. Since these LEDs are also very cheap, the cost benefit of using just the APTBD3216SURKCGKC-01 LED is thrown out the window.

Table 3.2.10: LEDs Comparison

Features	APTBD3216SURKCG KC-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

3.2.8 Power Supply

Having established that Switching Power Supplies (SMPS) are the best technology choice for our project due to their high efficiency, we now focus on selecting a 12V 5A SMPS model. The power supply needs to deliver a stable 12V DC output, which is essential for powering the voltage regulator. This regulator will then step up the voltage to 12.6V, the required voltage for the charger controller. The charger controller is responsible for managing the battery charging process for the 3S BMS and ensuring safe and efficient charging of the lithium-ion battery pack. The decision to use a 12V power supply instead of directly using 12.6V is driven by the fact that 12V is a common, widely available voltage for power supplies, and it provides flexibility for different system requirements. The voltage regulator ensures that the voltage is stepped up to the precise level required for the charger controller and the rest of the system.

Table 3.2.11: Power Supply Comparison

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
Certifications	Low to Moderate	Low to Moderate	High
Reliability	High	High	Moderate
Price	\$11.99	\$49.99	\$9.99

After evaluating multiple power supply options, the ALITOVE 12V 5A Power Supply was selected as the best choice for our project due to its balance of efficiency, reliability, and cost-effectiveness. With a high efficiency, it ensures minimal power loss while providing a stable 12V output at 5A, making it ideal for powering the system. The ALITOVE also includes essential safety protections, such as over-voltage, over-current, and short-circuit protection, which ensures the longevity and reliability of the system. This combination of features makes the ALITOVE a practical and reliable solution for our power requirements.

3.2.9 Voltage Regulation

After analyzing various voltage regulation technologies, we decided to use switching voltage regulators for the majority of the system. Switching regulators, specifically buck converters and boost converters, were chosen due to their high efficiency and ability to handle variable input voltages while maintaining stable output voltages. The use of buck converters will allow us to step down the voltage from the 12V input supply to the required 5V for powering the Raspberry Pi and ultrasonic sensors. Additionally, a 3.3V regulator will be used for the ESP32 and LEDs, ensuring they receive the proper voltage for optimal performance. On the other hand, boost converters will be used for the charger controller to step up the 12V input to 12.6V, which is necessary for charging the 3S battery pack. For this project, we need different regulators to manage the various voltage requirements and input conditions. Since we may be switching between battery power and mains power, it is essential that the voltage regulators can handle unregulated input voltages and provide stable outputs for the Raspberry Pi, ESP32, ultrasonic sensors, and LEDs.

Table 3.2.12: Buck Converter Comparison

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
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Table 3.2.13: Boost Converter Comparison

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

For the Buck Converter, after comparing several models, the LM2596 Buck Converter was selected as the most suitable option for the project. This model offers the flexibility of configurable output for either 3.3V or 5V, making it ideal for powering components like the ESP32 (3.3V) and Raspberry Pi (5V). With a wide input voltage range and 3A output current, the LM2596 provides a high efficiency and low heat dissipation, which is important for maintaining stable operation in our system.

For the Boost Converter, the LM3478 was selected as the best fit for our system. This IC is well-suited for applications such as battery charging, as outlined in its datasheet. The LM3478 can efficiently step up the input voltage to 12.6V, which is required to charge the 3S lithium-ion battery pack using the charger controller. With a high efficiency, the LM3478 ensures excellent power conversion with minimal energy loss and low heat generation, which is crucial for maintaining the long-term performance of the system. Additionally, the LM3478 provides a compact design and delivers a stable output across a wide range of input voltages. The output current can be easily programmed with a single external resistor, providing flexibility for different charging needs and optimizing the power delivery. This feature makes the LM3478 an ideal choice for charging applications where a regulated output and customizable current are necessary.

3.2.10 PowerPath Controller

After evaluating various PowerPath controller technologies and selecting Dedicated PowerPath Controller ICs, we focused on finding the most suitable model for our project. We researched different PowerPath controllers and found the LTC4412 PowerPath to be the best option for efficiently managing power transitions between the primary power source and the backup battery while maintaining high efficiency and reliable battery protection. The LTC4412 offers an integrated solution that includes MOSFET control, voltage regulation, and battery charging management. This makes it ideal for our system,

which requires seamless power switching, safe battery charging, and minimal heat dissipation.

Table 3.2.14: PowerPath Controller Specification

Feature	LTC4412 PowerPath
Input Voltage	2.5V - 28V
Output Voltage	$V_{in} \pm 0.3V$
Output Current	Wide Range of Current
Brand	Analog Devices Inc.
Price	\$5.91

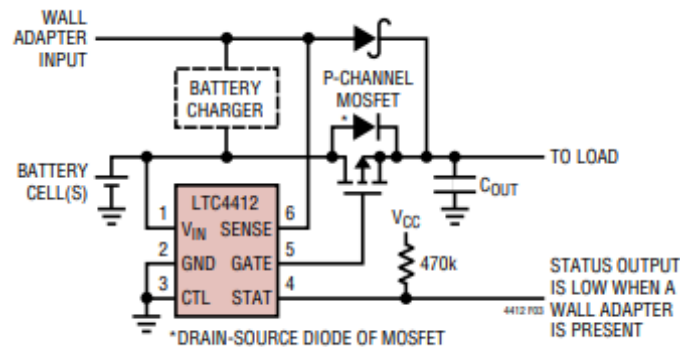


Figure 3.4: Automatic Switchover of Load Between a Battery and a Wall Adapter.
<https://www.analog.com/media/en/technical-documentation/data-sheets/ltc4412.pdf>

The LTC4412 PowerPath Controller was selected as the most suitable choice for our project, based on its high current handling, efficiency, and advanced protection features. The output current is determined by the MOSFET integrated within the LTC4412. This MOSFET enable efficient power switching with minimal voltage drop, allowing the controller to handle higher current loads without generating excessive heat. This is crucial for maintaining high efficiency and preventing thermal issues during operation. The LTC4412 also includes built-in protection features such as overcurrent, overvoltage, and thermal protection, ensuring the safety of both the battery pack and the rest of the system. With its compact design and integrated power management, the LTC4412 is the best choice for our system, offering reliable performance and seamless switching between the primary power source and the backup battery.

3.2.11 Charger Controller

After selecting PWM (Pulse Width Modulation) technology as the most suitable charging method for our project, the next step is to evaluate specific PWM-based charger controller ICs that can efficiently manage the charging of our 3S lithium-ion battery pack. The PWM charger controllers were chosen due to their simplicity, cost-effectiveness, and ability to

work well with our regulated 12.6V input. These controllers are ideal for systems where the input voltage is relatively stable and does not require the advanced flexibility of MPPT technology, which is better suited for solar power or other highly variable sources. We will compare three PWM-based charger ICs, focusing on their efficiency, charging current capabilities, protection features like overcurrent protection and thermal management, and cost. This comparison will help us identify the most appropriate model for efficiently charging our battery pack while maintaining safety and reliability in the system.

Table 3.2.15: Charger Controller Comparison

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

The BQ24130 was selected as the most suitable charger controller for our project due to its high efficiency (~90%), adjustable output voltage, and ability to support up to 3A of charging current, which is well-suited for our 3S lithium-ion battery pack. This controller integrates essential protection features such as overvoltage, overcurrent, and thermal protection, ensuring the safe operation of both the battery and the system. Additionally, the BQ24130 is a standalone (RC-settable) charger, making it easy to configure without the need for additional programming. While the LT1511 and BQ24650 offer similar features, the BQ24130 provides the best combination of cost-effectiveness, simplicity, and performance for our system's charging requirements.

3.2.12 Batteries

After selecting Lithium-ion (Li-ion) batteries in Part 3.1 for their high energy density, reliable performance, and long cycle life, we focused on identifying the most suitable 3S Li-ion battery pack for our system. The 18650-battery format is a popular and widely used choice in Li-ion battery applications due to its standardized size, making it easy to integrate into modular battery packs. The 18650 cells offer a good balance between capacity,

discharge rate, and safety, making them ideal for systems that require high power and long-term reliability, such as electric vehicles, power tools, and energy storage systems. In this section, we will evaluate three specific models of 18650 Li-ion cells that can be used to form a 3S battery pack. We will compare their capacity, discharge current, energy density, and cycle life to ensure that the selected model meets the charging and performance requirements for our project while also integrating seamlessly with our Battery Management System (BMS).

Table 3.2.16: Batteries Comparison

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

After comparing the three Li-ion battery models, the NCR18650B is selected as the most suitable option for our system. This model provides the best balance of capacity, energy density, and cycle life for our project needs. With a capacity of 3400mAh and energy density approximately 240 Wh/kg, it ensures a long runtime and efficient energy storage. While its discharge current of 6.8A is not as high as the INR18650-25R, it is still sufficient for the current demands of our system. Additionally, the cycle life approximately 250-500 cycles ensures that the battery will provide reliable performance over time.

3.2.13 Battery Management System (BMS)

After selecting the Centralized BMS architecture, we focused on finding a specific module that could reliably manage and protect our 3S lithium-ion battery pack. The BMS needed to support cell voltage monitoring, passive balancing, and protection features such as overvoltage, undervoltage, overcurrent, and short-circuit protection. Since our system does not require advanced communication features or scalability, we prioritized a compact, efficient, and easy-to-integrate solution. Based on these criteria, we selected the HX-3S-FL25A-A BMS as the most appropriate BMS for our project.

Table 3.2.17: HX-3S-FL25A-A Specification

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

The HX-3S-FL25A-A was selected as the Battery Management System (BMS) for our project due to its simplicity, reliability, and compatibility with our fixed 3S lithium-ion battery pack. It offers all essential protection features, including overcharge, overdischarge, overcurrent, and short-circuit protection, ensuring safe operation of the battery during both charging and discharging cycles. The module supports passive cell balancing, which helps maintain consistent voltage levels across the cells and improves overall battery health. With a continuous current rating of up to 25A, it comfortably meets the current demands of our system. Additionally, the HX-3S-FL25A-A has a compact form factor, requires no configuration, and is cost-effective, making it ideal for embedded applications like ours where space, simplicity, and reliability are key.

Chapter 4 - Standards and Design Constraints

This chapter will focus on the standards and constraints that are a part of our project. For the first section, we focus on the industry standards that we will be using for our project and go in depth into each one. For the second section, we will talk about our design constraints that we faced for our project. In the third section, we will end the chapter by talking about the remaining constraints that we faced that we did not put in the second section.

4.1 Industrial Standards

4.1.1 PCB Design Standards

In the design and manufacturing of printed circuit boards (PCBs), adherence to established IPC standards is crucial to ensure the design is functional, reliable, and compatible with mass production processes. The IPC-2221 standard provides the generic requirements for designing printed boards, emphasizing design for manufacturability (DFM) to ensure that the PCB is easy to produce. It covers key considerations such as signal integrity, thermal management, and component layout, which are critical for maintaining performance and minimizing manufacturing challenges. Additionally, the IPC-2221 standard outlines the importance of optimizing the design to ensure that the PCB can be produced efficiently and meets electrical and mechanical requirements.

To ensure that the PCB is suitable for mass production, we must also consider the manufacturing capabilities of the PCB fabricator. For our project, we will be working with JLC PCB, a well-known PCB manufacturer that adheres to IPC-2221 guidelines and offers specific design standards to guarantee high-quality and reliable PCBs. JLC PCB supports multi-layer designs, offers a range of PCB thicknesses, and provides various surface finishes, such as HASL and ENIG. These surface finishes ensure strong solder joints and electrical performance for component placement and soldering. In addition to meeting IPC-2221, JLC PCB also performs automated optical inspection and electrical testing to ensure that the finished PCBs are free of defects, thus guaranteeing the reliability of the design. By following IPC-2221 and JLC PCB's design guidelines, we ensure that our PCB is not only optimized for manufacturing but also meets industry standards for quality and performance, ultimately contributing to the overall success and safety of our project.

Now, let's break down the core aspects of IPC-2221. These guidelines focus on making sure that the design is easy to manufacture, safe, and efficient, and that the board will function properly in real-world applications.

1. **Design for Manufacturability (DFM):** Ensures the design is optimized for easy production, reducing the likelihood of errors and making the PCB simpler to assemble.
2. **Signal Integrity:** Ensures high-speed signals are stable and clean by considering trace width, grounding, and shielding to reduce electromagnetic interference.
3. **Thermal Management:** Ensures the PCB doesn't overheat by using thermal vias, heat sinks, and larger copper areas to effectively dissipate heat.

4. **Electrical and Mechanical Requirements:** Covers the voltage, current, and trace dimensions to ensure the board meets operational needs and can handle stressful environments.
5. **Component Placement:** Optimizes component layout for efficient assembly and to minimize short circuits and signal interference.

By following IPC-2221, designers can create high-quality, manufacturable PCBs that will work efficiently and cost-effectively in the production environment. This standard is especially important for our project, as it ensures the PCB will not only meet functional and performance specifications but also be easy to produce and safe for use in various applications.

4.1.2 WIFI Standards

Wi-Fi will be our main method of wireless communication between the ESP32 and Raspberry Pi 4 to the database. Wi-Fi is a very important technology that allows wireless communication between devices and is practically available almost everywhere nowadays which is handy if you want to access the internet. The IEEE SA, or the Institute of Electrical and Electronics Standards Association, developed the IEEE 802.11 technical standard. Commonly known as Wi-Fi, it has been around since 1997 and is still being added onto with newer standards of Wi-Fi still being developed today. Wi-Fi started off only supporting wireless data transmission of up to 2 Mbit/s while using just the 2.4 GHz radio spectrum, while the latest Wi-Fi standard now is able to support up to 23 Gbit/s and connections to 2.4 GHz, 5GHz, and 6GHz frequency bands.

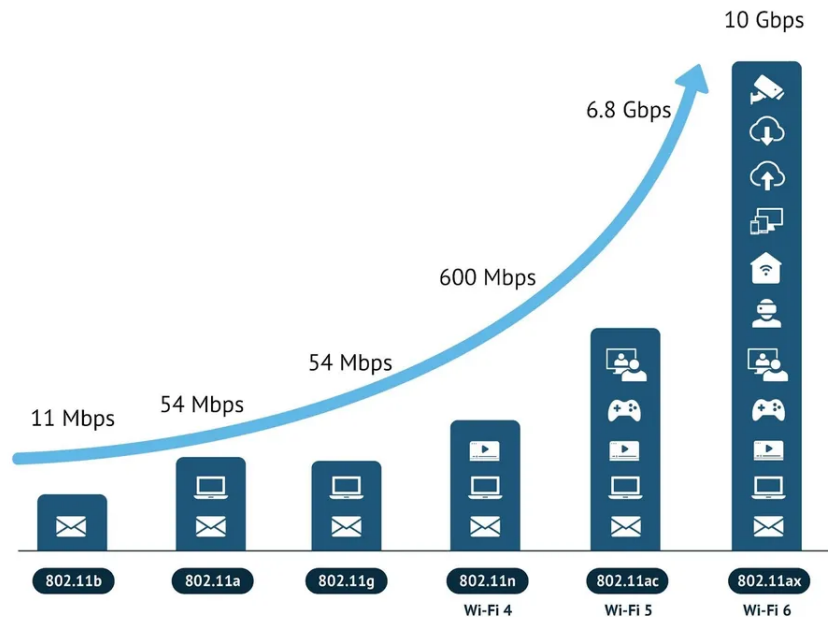


Figure 4.1: Wi-Fi Standard Evolution

The 802.11 standard has stations, which are just all the devices that are connected to the Wireless Local Area Network (WLAN). These devices can be sorted into two categories, either a wireless access point like wireless routers or a client like computers or phones. The wireless access point acts as a bridge for both wireless and wired communications, which

then has to listen to the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol so that the wireless data being transmitted between all the devices are not colliding if multiple devices send out data close to each other. This is important as parking garages will have many cars and people go in and out, so their data transmissions should not interfere with our parking management system. The ESP32 supports the standards 802.11b/g/n and the Raspberry Pi 4 supports the standards 802.11b/g/n/ac, so that means we will likely have to use a 2.4 GHz network for the ESP32. This is not a problem as 2.4 GHz networks tend to deal with thick concrete walls better than 5 GHz networks, which is where our devices will be near in the parking garage. Since our project will include a website for purchasing permits, we do not want the credit card information of the customers to be not secure. For security, there are a couple wireless security protocols that are implemented in these access points. The most outdated one is Wired Equivalent Privacy (WEP) and is the weakest security protocol as it only had a 40-bit pre-shared encryption key and was very easy to decipher the 24-bit initialization vector (IV). Wi-Fi Protected Access (WPA) was then created to be the alternative to WEP that has stronger security by providing a larger 48-bit IV, 256-bit encryption keys with unique keys for each data packet being sent out, and more features that made it a lot safer compared to WEP. WPA is still being developed today, even having a third version, WPA3, being the most secure wireless protocol currently.

4.1.3 CSI Standard

The MIPI (Mobile Industry Processor Interface) Camera Serial Interface (CSI-2) is one of the most widely used camera interface standard that facilitate high speed communications between the image sensor and the processor. The MIPI CSI-2 defines a point-to-point connection between a camera's image sensor on one end, such as the CMOS sensor, and an image signal processor on the other end. It does such high-speed data transmission communication by utilizing the MIPI D-PHY or MIPI C-PHY physical layer.

A MIPI CSI-2 system Architecture consists of three main parts. The camera sensor (transmitter/Tx), image processor (Receiver/RX), and the MIPI CSI-2 bus. The transmitter is responsible for capturing the images and converting them into digital signals. After that, these digital signals get transferred through the data bus multiple lanes as packets where they reach the receiver/RX. The receiver, which is the image processor, is responsible for processing the received data further so it can be used in applications such as computer vision or object detection.

The physical layer (PHY) of MIPI CSI-2 plays an important part in determining the data transfer efficiency. The MIPI CSI-2 can operate on two different types of physical layers: MIPI D-PHY or MIPI C-PHY. The MIPI D-PHY is a simple source-synchronous PHY that uses a single clock lane for synchronization and a variable number of data lanes (from 1 to 4) for transmitting image data. It also employs differential signaling to improve noise immunity and signal integrity. One of the key features of MIPI D-PHY is its use of a dedicated clock lane on top of the multiple data lanes. MIPI D-PHY is also scalable as it can operate from 1 to 4 data lanes with speed reaching up to 2.5 Gbps per lane, for a total maximum (based on 4 data lanes) transfer rate of 10 Gbps. On the other hand, MIPI C-PHY is a newer layer protocol introduced in 2014. Its introduction brought a new encoding

technique and multi-level signaling eliminating the need for a specific clock lane where the clock lane is embedded in the data stream, reducing complexity. One of the key features of MIPI C-PHY is its use of data lines known as Trio, where each trio consist of three signals: A, B, and C. It uses 16/7 encoding (2.28 bits per symbol) for improved data throughput leading to a reduction in power usage of up to 50% compared to D-PHY.

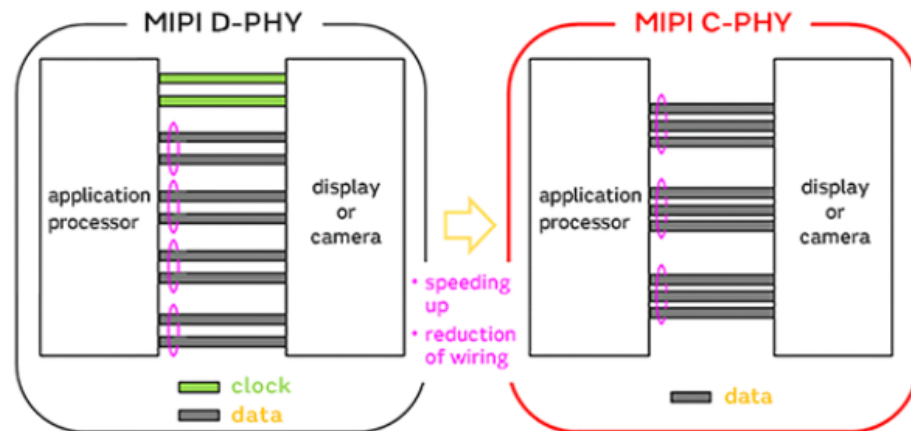


Figure 4.2: Key Differences between D-PHY and C-PHY

Table 4.1.1: D-PHY and C-PHY Comparison Table

Feature	MIPI D-PHY	MIPI C-PHY
Signaling	Differential (1 clock + multiple data lanes)	Three-phase encoding (trios)
Data Lanes/Trio	1 to 4 data lanes	1 to 3 trios
Clock Lane	Separate clock lane required	Embedded in data
Max Data Rate	2.5 Gbps per lane (10 Gbps with 4 lanes)	3.5 Gbps per trio (~17.5 Gbps with 3 trios)
Bits per Symbol	1 bit per symbol	$16/7 \approx 2.28$ bits per symbol
Power Consumption	Higher	~20-50% lower than D-PHY
Lane Flexibility	Fixed lane structure	Each trio operates independently
Pin Efficiency	Requires more pins per bandwidth	40% fewer pins for the same bandwidth
Signal Encoding	No encoding	16/7 encoding improves efficiency

A system can communicate with CSI-2 format by using two types of packets lengths. Both packet lengths are usually used in the same system as each one of them serve a different purpose. Short packets are typically used for control information, while long packets are used to transmit the data of the actual image.

Short Packets include fields for:

- Start of Transmission (SoT)
- Virtual Channel (VC) & Data Type (DT)
- Data Field (frame number, synchronization)
- Error Correction Code (ECC)
- End of Transmission (EoT)

Long Packets include fields for:

- Start of Transmission (SoT)
- The Packet Header (32 bits)

It contains:

1. **Virtual Channel (VC):** Allows multiple cameras to share the same CSI-2 interface.
 2. **Data Type (DT):** Defines the format of the payload, such as:
 - RAW8 (0x2A) – 8-bit Bayer pattern data
 - RAW10 (0x2B) – 10-bit Bayer pattern data
 - RGB888 (0x24) – 24-bit RGB
 - YUV422 (0x1E) – YUV format
 3. **Word Count:** Specifies the size of the payload in bytes.
- Payload (Pixel Data)
 - Packet Footer (PF) – CRC. A 16-bit Cyclic Redundancy Check (CRC) is added to detect corrupt data.

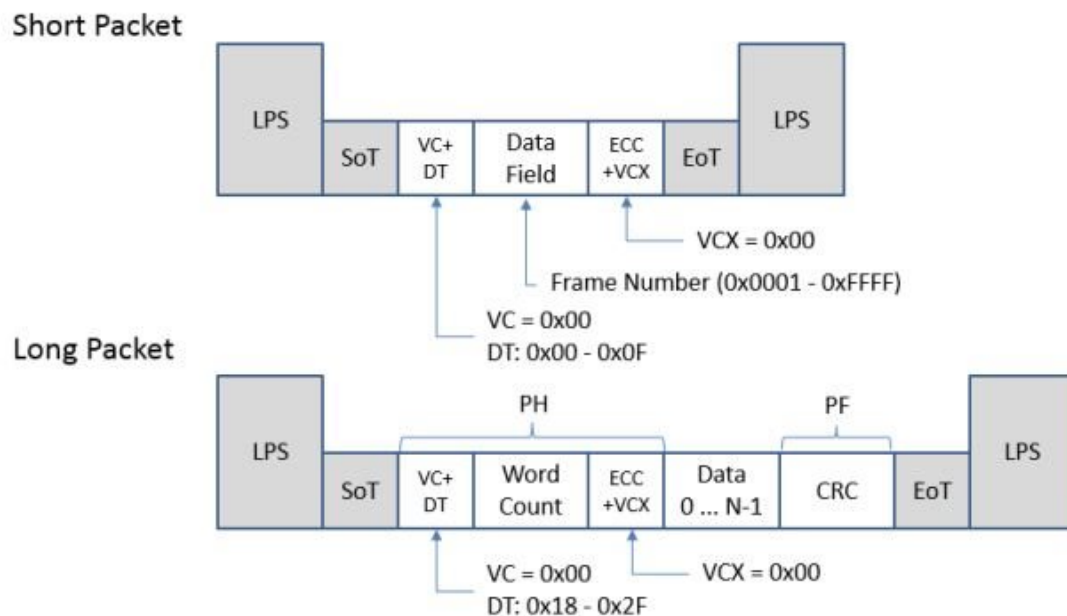


Figure 4.3: Short and Long Packet Visual

4.2 Practical Constraints

4.2.1 Time

The main constraint of our project is time, especially since we are doing Senior Design 1 in the Spring and Senior Design 2 in the summer. It is less time compared to Fall-Spring Senior Design students, who typically have about 10-11 months to work on their project. Since we are Spring-Summer, we are allowed about 8 months to brainstorm for an idea, hone into that idea and research about it, develop a prototype, and create the final product. To not get overwhelmed by the short amount of time we have to create a fully functioning system, we have thought about ways we could work better as a group to manage our time correctly.

One of the ways we have better managed our time is to have weekly group meetings on Discord. These meetings are meant for our members to state how they are doing on the project and what they have done so far. It allows us to make sure each member is contributing enough each week or else we would fall behind. The good thing about modern ways of communication is that even if we cannot meet in person, we will meet over Discord to talk about and even show what we have done. This helps create a mutual understanding between the members to participate in the project and not to procrastinate. Most meetings are usually around 30 minutes to an hour, which is way more than enough time to discuss any questions, concerns, or just comments that a member has. The good thing about Discord as well is that we have our own Discord server with multiple chats to organize our findings and anything that we thought is relevant to our project. This helps each member share what they have found with the others without necessarily needing to schedule a meeting to talk about it, it just allows them to put the ideas down and talk about it later, possibly in those weekly meetings.

Another way we managed our time better is that we got a head start on things pretty quickly, by coming up with an idea for our project as soon as we formed the group. This allowed us more time to brainstorm the ways we can implement that idea in a way that is feasible for Senior Design, while trying to implement the most features for our ideas that we can. Starting early allows us to clearly see what features are the most important to us and what features we don't necessarily need to implement, which saves more time for prototyping and seeing what works and does not. Starting early beats the problem of having less time to work on our Senior Design Project since we technically have a head start to our project.

One other item that has helped us with time is having a dedicated group chat to talk more regularly about the project. Our Discord server is used mostly for meetings and putting information we found that is relevant to our project into the chats. For our main group chat, we use WhatsApp to communicate directly to each other whenever we need to. Whenever a member had a question, they would just ask in the group chat and someone else would reply rather quickly since WhatsApp is just a messaging app on our phones, so we are more inclined to reply faster. This helps with time as it can allow us to quickly ask questions and get a quick answer without waiting for the regularly scheduled weekly meetings to roll around. This lets the member not get stuck worrying about that question and moves them along in the project.

The last way that we are able to manage our time well in this project is that in addition to the weekly Discord group meetings, some members of our team attend the same classes. This then creates a secondary group meeting where some members can talk about the project and their ideas, then they can relay the talk they had to the member that was not in that specific class. This means that we are able to talk in person as well instead of just having online meetings. Later on, we will transition these weekly Discord meetings to in person meetings so that we all can physically work on the project and collaborate together.

4.2.2 Economic

For our project, the economic design constraint is a significant factor that shapes key decisions in our system's design. We are working within a budget that necessitates balancing cost-effectiveness with performance. This means we must choose components that meet our technical requirements while keeping the overall project affordable. The challenge is to select high-performance components, such as the 3S lithium-ion battery pack, charger controller, Raspberry Pi, ESP32, and PCBs, without exceeding the available budget. While some components like the Raspberry Pi are necessary for the computational needs of the project, they come with a higher cost compared to simpler microcontrollers, so we must ensure that the selection of all components fits within the financial constraints.

One major consideration is the battery selection. The 3S lithium-ion battery pack provides the necessary voltage and capacity for our project but represents a significant portion of our budget. The Battery Management System (BMS), necessary for safe operation, adds another layer of cost. Selecting a cost-effective BMS that provides overcharge protection, cell balancing, and other safety features is essential to stay within the budget. A similar challenge arises with the charger controller; while high-efficiency controllers are important for maintaining performance, we need to balance performance and cost. For example, the BQ24130 charger controller is a good choice due to its cost-effectiveness and ability to provide the required charging performance, but it also has limitations when compared to more advanced controllers.

The modular PCB design also contributes to the economic constraint. By opting for multiple, removable PCBs that allow for easier maintenance and future upgrades, we increase the overall manufacturing cost. Each separate PCB will need to be designed, fabricated, and tested, which requires careful planning to ensure the costs are kept reasonable. Despite the extra costs associated with a modular approach, it provides the advantage of flexibility and ease of maintenance in the long run, which justifies the added expense.

To mitigate these constraints, we will focus on component selection by conducting thorough research to identify the best value-for-money options. By working with manufacturers like JLC PCB, who offer affordable and high-quality PCBs, we can ensure the project stays within budget while maintaining a high level of quality. However, it's important to note that shipping costs can also add a significant expense to the project. To address this, we will select suppliers who offer competitive pricing while minimizing shipping fees through bulk orders or using local suppliers when possible. Additionally, we

will allocate a portion of the budget as a contingency fund to cover unforeseen expenses or the replacement of defective parts during testing and development.

Ultimately, while the economic constraint presents challenges, it is manageable through careful planning, research, and budgeting. The project will meet its goals by optimizing costs and performance to ensure the system is both functional and cost-effective without compromising on reliability or quality.

4.2.3 Environmental (Impact of Lighting Conditions)

To detect a license plate number, it is essential that the image captured be of enough high quality so the detection model can be able process it. Whatever the image quality is, it is essential for it to be above a certain threshold so that the license plate recognizer whether that is a custom model or commercial model such as OpenALPR be able to process it. A major issue that can affect the image quality is the lighting conditions, whether that is sunlight glare, low light conditions (nighttime), shadows from nearby vehicles or objects, or overhead lights glare (fluorescent lights). If the system is not able to detect an image of enough high quality, then the whole detection software and system will be rendered useless with no plate number detected. So, to put it simply, lightning conditions is a major design constraint that we must face in our project. To solve such issue, we can follow a couple of design requirements to limit or minimize the effect of lights on our image quality. To solve the overexpose of the license plate due to the direct sunlight we can use an HDR camera to adjust the exposure dynamically. Another solution is to adjust the camera angle to avoid the direct sunlight, this can be done by a trial and error to find the best location where the cameras should be mounted. Another problem which is due to low light conditions can be easily solved by one of two solutions: either by using infrared cameras that are capable of capturing license plates in the dark, or by using bright overhead lights to brighten the garage.

4.3 Remaining Constraints

4.3.1 Sustainability

For our project, sustainability was one of the constraints that we thought about when deciding on the features of our project. We wanted to provide a parking garage management system that would not need to have any construction work done on the garage. This allows for easy installation of our product into existing garages as well, instead of needing to make sure that the parking garage installs our system whenever it is being built. This helps pre-existing parking garages gain these modern features, reducing the need to build another parking garage with these features.

One of our ideas for the backup battery system was to include solar panels, which means we would have renewable energy being used to charge the batteries and power the system. These solar panels would especially help with our BMS system by having continuous charging even if the power went out in the area, providing a longer run time of our project. Having solar panels could also mean less use of the grid for our electricity if the BMS system has the batteries fully charged, it could transfer some of the solar panel generated electricity to the system.

Another item that helps with sustainability is that we chose components that would last a long time and would not need to be replaced. These components can add up over time and would be contributing a lot to the landfill if we decided to use components that did not have a long life span. For example, choosing geomagnetic sensors, especially those with weatherproofing, could mean you would have to replace a large amount of those sensors everytime they run out of battery. Due to the way they are built to keep water out, these batteries inside those sensors can not be recharged, meaning full replacement of those sensors whenever the time comes. Using ultrasonic sensors means that they can have a longer life span since there is no need to replace the batteries, allowing the sensors to operate until they fail.

4.3.2 Ethical

In our license plate recognition system, it involves capturing driver's license plates at the entrance and exit of the garage and storing them in a database for processing. In addition, storing license plate numbers is accompanied by entrance and exit timestamps, vehicle picture and a user account information. This capturing and storing of a license plate and storing it in a database, raise an important ethical question regarding data integrity, surveillance and data misuse. To mitigate such a problem, our system must be California Consumer Privacy Act (CCPA) complaint. CCPA is a California state law that was first introduced in 2018 and has since then become an industry standard. The law states that a consumer, in our project that will be the driver, has access to three basic rights: Right to Know, Right to Delete, Right to Opt-Out. In the right to know section, as the name implies, the consumer has the right at any point to request a copy of all the personal information that a business has collected relating them. This includes everything from time of collection to the purpose of such collection. The second section, which is the right to delete, gives the consumer the authority to request all or part of their data to be delete from the business system. The third and final section, is the right to opt-out, which gives the consumer the right to deny permission of a business to sell their personal information. Essentially the business can still collect and use a consumer personal information, but they can't sell it to a third party. Another major ethical problem in our system is data security. What if the system is not secure enough where a hacker was able to access the database and steal or manipulate users' data? This can be solved by ensuring better data encryption, with role-based access controls to prevent unauthorized access.

4.3.3 Manufacturability

Manufacturability is an important constraint for our project, as we are limited by the available lab equipment and resources. As undergraduate students, we must design the system to be simple and efficient to produce with the tools at our disposal. The decision to use multiple, removable PCBs adds a layer of complexity, as each PCB will need to be individually fabricated and tested, increasing both production time and cost. While this modular approach provides flexibility and easier maintenance, it does require careful planning to ensure that the design remains cost-effective and easily manufacturable.

To manage these constraints, we will rely on external manufacturers like JLC PCB to handle the PCB production. This will help reduce the burden on our lab resources while

ensuring the PCBs meet quality standards. Additionally, we will select cost-effective components and streamline the design to minimize the complexity of assembly. By focusing on efficient designs and leveraging external support, we can ensure that the project remains within budget while meeting performance and reliability goals.

Chapter 5 – ChatGPT

This chapter will focus on ChatGPT and each member's experience using the LLM for help and assistance for this project. It will not only focus on the upsides of using something like ChatGPT for projects, but it will also include downsides that you may have to look out for. Since ChatGPT is getting more popular and more people use it, they need to understand that it is a helpful tool but should not fully rely on it as it can be incorrect. Each section will have one member's experience and examples of their ChatGPT use.

5.1 Tony's Experience

ChatGPT can be a very useful tool if used properly and with extra research. While search engines like Google can usually be handy when searching up popular things, it can be harder to find specific information about something that is not as popular. The current model of ChatGPT that everyone can use, though limited, is GPT-4o. It is now able to handle and scan over images that are being sent as a prompt, but I have not used that feature for my ChatGPT use for this project. My use with ChatGPT for this project so far is for research with technologies that I am not too familiar with and parts that are available for the technology we chose to use. Especially with parts that aren't talked about as much, it can be handy being able to ask ChatGPT for some recommendations to further research since it isn't always 100% correct, so I always make sure to double check and look the information up to make sure it is right.

For example, when I was looking for the differences between LED and LCD displays to find which display would be better to use for our project, it was hard to search on the internet. Everytime I would search for "LED vs LCD displays" on Google, it would show me TV and monitor technologies since those are the popular LED displays. ChatGPT helped me narrow it down when I submitted this prompt:

"For my display to show the number of free parking spots, should I use an LED or LCD display?"

It showed me a lot of different types of LED and LCD displays that I could further research and find information about. The only problem was that the information that ChatGPT provided with these displays were not the most accurate, leading me to further research into these displays to find the accurate details of them like power consumption. But that could be down to certain LED and LCD displays having different power consumption measurements than normal. I also wanted to know more about Dot Matrix displays as I wanted to see how they worked and what it was like to use them as I thought it would have been a bit more complicated, but it worked similar to how I imagined.

One example of how using ChatGPT was not that useful and led me to researching the topic on my own was when I was researching different types of LEDs. Since we decided on using SMD LEDs for our project, I wanted to see what kind of different SMD LEDs there are and what the comparisons between each LED is. I gave it the prompt:

"For the LED indicator for my project, what types of SMD leds should I compare?"

For this prompt, ChatGPT gave a table comparing a few different LEDs, but were not a specific product, as it just showed basic SMD LED types. The “types” of SMD LEDs listed were just the different package sizes of SMD LEDs, which is not what I wanted as I was hoping for specific LEDs that could be used in our project. This led me to searching for SMD LEDs on Digikey for the red and green indicators, where it had specifics about brightness for each LED and the package size that we hoped to use, which is 1206. Having the actual millicandela ratings on Digikey helped me compare the LEDs instead of having vague statements from ChatGPT that were not totally accurate sometimes.

One example that was beneficial for my research is that I did not know about the millicandela rating beforehand as I was used to the lumen rating normally used by light fixtures. This meant I could not tell if 100 mcd was bright enough or if I needed more. Using ChatGPT, I asked the prompt:

“What mcd rating for LEDs would be good for my project?”

It then answered, showing me millicandela values that would be adequate for indoor and outdoor use. To make sure it was correct, I tried searching up how millicandela ratings translate to actual visibility. Finding out that one Candela unit would be equivalent to the brightness of one candle, the values provided by ChatGPT seemed to be reasonable and I could try and base my LED research on finding those diodes that emit close to the values that it provided. As I have not had experience with testing LEDs and millicandela ratings, I only had to base it off my research so ChatGPT was very helpful for helping me gauge what kind of rating would be good for the LEDs I chose.

5.2 Mark’s Experience

As we delve deeper into research for our Senior Design project, we often rely on digital tools for quick answers, in-depth research, and technical insights. Two of the most commonly used platforms for this purpose are ChatGPT and Google Search. While both are powerful tools for retrieving information, they differ significantly in how they present data, the depth of their responses, and how useful they are for specific types of queries.

ChatGPT is an AI-powered conversational model that can generate human-like responses based on the prompts given to it. It is designed to understand context, answer questions, and provide explanations across a broad range of topics. However, its responses are not always rooted in the most up-to-date data or specific product recommendations, and it may require further cross-referencing. On the other hand, Google Search is a widely used search engine that pulls from an extensive index of web pages and resources. It provides links to sources, products, articles, and academic papers that are often very current and detailed. However, it can sometimes overwhelm users with too many results and irrelevant links.

One example of a question I asked during my search for information to help with the Senior Design project was to better understand the differences between voltage regulators, specifically the trade-offs between linear and switching regulators in terms of efficiency, applications, and overall performance. This would help me choose the most suitable components for the project, ensuring both reliability and cost-effectiveness.

"What are the differences between voltage regulators?"

The response from Google Search provides a clear and concise overview of the two types of voltage regulators. It explains that linear regulators are simpler, less efficient, and best suited for low-power and low-noise applications, while switching regulators are more complex but much more efficient, particularly in high-power or battery-powered applications. Google also includes some basic examples like buck, boost, and buck-boost converters for switching regulators, but it does not provide in-depth technical explanations or specific product recommendations. While the search result is useful for general understanding, it lacks the detailed analysis that might be needed for making specific component selections for the project.

ChatGPT, on the other hand, provides a much more in-depth explanation. It describes the operation of both linear and switching regulators, including how linear regulators dissipate excess voltage as heat and how switching regulators store and release energy efficiently using components like inductors and capacitors. ChatGPT also provides detailed examples of buck, boost, and buck-boost converters, explaining their specific applications and advantages in certain scenarios. Additionally, ChatGPT offers the flexibility to tailor responses based on the project's needs, suggesting the most suitable types of regulators for high-power or low-noise requirements, which makes it a more valuable resource for technical decision-making.

Another example of a question I asked during my research was to explore the most common types of batteries used in various applications, specifically to find out which type is most commonly used in backup power systems.

"What are the most common types of batteries?"

The response from Google Search provided a comprehensive list of the most common disposable and rechargeable batteries. It categorized them into two groups, with alkaline and lithium-ion batteries being the most widely used in household devices and portable electronics, respectively. Alkaline batteries are commonly used in low-drain devices, while lithium-ion batteries are prevalent in smartphones, laptops, and electric vehicles due to their high energy density and rechargeability. The response also mentioned other disposable batteries like zinc-carbon and lithium, and provided an overview of rechargeable batteries such as NiMH, lead-acid, and NiCd, which have specific use cases in automotive and backup power systems. This information was useful for understanding the different types of batteries and their typical applications, though it remained fairly general.

When I asked ChatGPT the same question, it provided a more in-depth explanation of the different battery types and their specific uses in various applications. ChatGPT not only identified the most common disposable and rechargeable batteries but also discussed their advantages, limitations, and suitability for particular tasks. For example, it highlighted that lithium-ion batteries are widely used in backup power systems due to their high energy

density, long lifespan, and rechargeability, making them an ideal choice for uninterruptible power supplies (UPS) and solar energy storage. It also explained that lead-acid batteries are still commonly used in larger backup systems due to their cost-effectiveness and ability to provide high currents.

Another example of a question I asked during my research was to compare PWM and MPPT charger controllers to understand which one would be more suitable for a system that uses regulated input voltage.

"What are the main differences between PWM and MPPT charger controllers, and which is better for a system that uses regulated input voltage?"

When searching for the differences between PWM and MPPT charger controllers, Google provided a straightforward comparison. It highlighted that MPPT controllers are more efficient, especially in systems where the solar panel voltage is higher than the battery voltage, making them ideal for high-power applications. For a system with regulated input voltage, Google suggested that PWM controllers could be sufficient since they are simpler and more cost-effective when the input voltage is stable. However, MPPT controllers were still recommended for their ability to maximize energy extraction and handle a wider range of voltages, even though they come at a higher cost. While this overview was useful, it lacked specific technical insights into how each type performs in systems with regulated input voltage.

When I turned to ChatGPT for the same question, it provided a much more detailed and tailored explanation. ChatGPT described how MPPT controllers use DC-DC converters to adjust and optimize power transfer, making them significantly more efficient than PWM controllers in systems with regulated input voltage. It explained that while PWM controllers work well when the input voltage is stable and closely matches the battery's voltage, they waste energy by dissipating excess voltage as heat. ChatGPT emphasized that MPPT controllers would still be beneficial even for systems with regulated input voltage, as they maximize the energy harvested and can handle slight variations in input voltage without compromising efficiency. Additionally, ChatGPT suggested several types of controller ICs, providing options commonly used in solar applications and battery charging systems.

For the first two prompts, regarding voltage regulators and batteries, both ChatGPT and Google Search proved to be helpful in providing valuable insights. ChatGPT offered detailed explanations and suggestions, while Google Search provided clear comparisons and additional context, allowing me to narrow down the options and make more informed decisions for the project. However, when it came to the third prompt regarding the charger controller, I found that I needed to go a step further in my research. While ChatGPT and Google provided general recommendations, I had to dive deeper into datasheets and specific IC details to identify the best option for our system. I spent time searching for charger controller ICs directly on manufacturer websites, like Texas Instruments, to ensure I selected the most appropriate component for our design requirement.

5.3 Chris's Experience

Using large language models like ChatGPT proved to be an invaluable tool throughout the research part of this project. Although traditional search engines can provide more information, they usually lack the ability to structure all the technical details in an easily readable manner. By using large language models like ChatGPT, it sped up the research process and gave me options to use in our project that I would have not known otherwise. Besides ChatGPT, other companies also provide their own AI tools, some of the options are Gemini (by Google), Claude AI, and Perplexity. But due to my previous experience with ChatGPT, on top of its well-known reputation as a leader in the AI market where it always outperforms its competitors in numerous benchmarks, I decided to use ChatGPT to help me do the research of this project. However, despite ChatGPT being a good starting point in my research, I still had to do my own research to verify the information that it was providing me.

One of the most helpful applications of ChatGPT where it was beneficial to my research was during the selection of the license plate recognition model and OCR. I needed to identify the recognition models that provide balance between speed, accuracy, and power consumption. At first, I searched online through Google search engine for "best license plate recognition models" where it yielded a lot of results that are scattered through different websites without direct comparisons. Instead, I used ChatGPT by entering the following prompt:

"What are the best object detection models for license plate recognition?"

ChatGPT provided me with well-structured response that compared the three models: YOLO, Faster R-CNN, and SSD. While generally the description of each model was accurate, when cross reference each model with websites on Google, I found them to be more detailed and better at explaining the technicality of each model. So ChatGPT was more of a tool that helped identify the models but still required more research from my part to better understand how they actually work.

Another instance where ChatGPT was helpful was during the selection of the database to store the detected license plates. I already had previous experience with using an SQL database particularly MySQL, but ChatGPT introduced to me a new type of database that I didn't know of, which is NoSQL. I initially enter the following prompt:

"Which database is better for real-time license plate recognition?"

The response provided me with two types of databases: SQL and NoSQL. It also gave me three databases' providers: MySQL, MongoDB, or PostgreSQL. This was the first time I was introduced to the idea of a NoSQL database, and upon further research and consulting MongoDB website, I decided to select the NoSQL database MongoDB as our choice of database due its simplicity and efficiency. So, in this instance ChatGPT was extremely helpful where it introduced me to new concepts that I did not off before.

While ChatGPT was helpful in some areas, I found instances where it struggled to provide up to date information leading to inaccuracies. For example, while searching for IP cameras to use for our license plate detection, I asked it the following:

"What are the best IP cameras for license plate recognition in a parking garage?"

It provided me with a list of IP cameras to use of which are: Hikvision DS-2CD4085F and Dahua IPC-HFW7442H-Z4. At first, they both seemed like viable choice to use in our project, but upon further research it turned out that both IP cameras are produced by companies in China that are banned in USA due to security concerns. This highlighted the limitation of LLMs, specifically ChatGPT due to its outdated information.

Another instance where ChatGPT was helpful, is determining the type of server to use to host our database. I entered the following prompt:

"Compare local server deployment vs. cloud-based deployments for a real-time license plate recognition system"

It provided me with the comparison of local and cloud-based servers with pros and cons of each. It also provided me with numerous options for the cloud-based server including Amazon AWS, google cloud, and MongoDB Atlas. Although for the most part it was helpful, ChatGPT did struggle with inaccurate data when asked about the pricing of each server. So, although it was a good starting point, I eventually still had to review each server selection website to look for the most accurate price data.

Overall, my experience with ChatGPT, an LLM tool, was mostly positive. It served as an excellent starting point in my research, where it introduced me to new concepts and helped me with comparing different parts and models. However, it also has its own limitation particularly with outdated information that often produce inaccurate data. So, I learned that it is essential to also do our own research, and that ChatGPT is not a replacement for technical documentation, but a complement to it.

Chapter 6 - Hardware Design

This chapter presents the hardware design of the project and focuses on how all components are integrated into a complete and functional system. It is organized into two main sections. The first section is the Subsystem Block Diagram, which provides a high-level view of the system architecture. The second section includes the Schematic Diagrams, which detail the electrical connections for each part of the system. These include the voltage regulators, PowerPath Controller, Charger Controller, Battery Management System (BMS), ultrasonic sensors, LED indicators, ESP32 microcontroller, and the Overall System Schematic.

6.1 Subsystem Block Diagram

The Subsystem Block Diagram (Figure 6.1) provides a detailed view of how the primary components of the system are interconnected. The process begins with the Power Supply, which is responsible for providing the initial power to the system. This power is then fed into the Boost Converter, which steps up the voltage to the required level. The Boost Converter outputs power to both the PowerPath Controller and the Charger Controller. The PowerPath Controller plays a key role in managing the flow of power, ensuring smooth transitions between the primary power source and the backup battery as needed. The Charger Controller, in coordination with the Battery Management System (BMS), regulates the charging process, making sure that the battery is charged safely and efficiently. To provide stable power to other critical components, such as the Raspberry Pi, ESP32, and sensors, voltage regulators are used. These regulators ensure that each component receives the correct voltage for optimal performance.

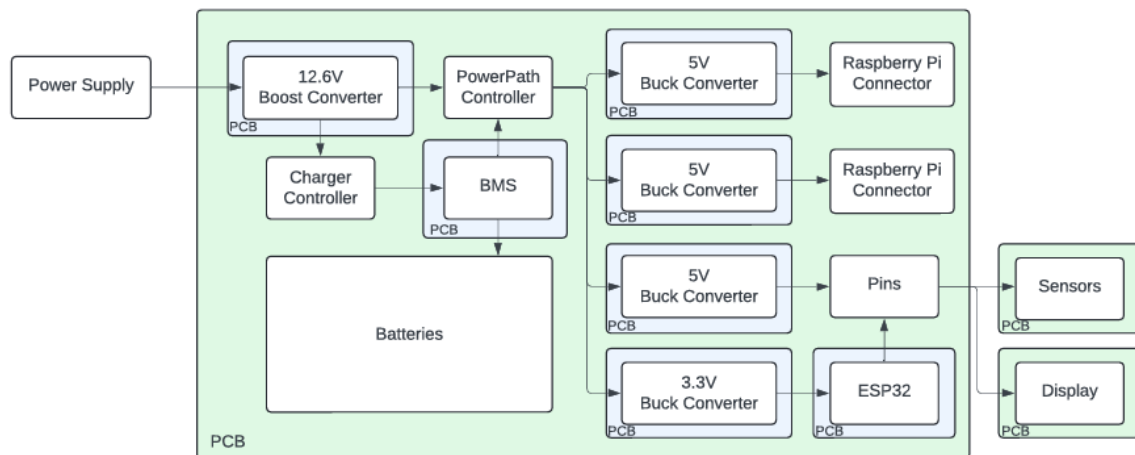


Figure 6.1: Subsystem Block Diagram
by Authors

6.2 Schematic Diagrams

6.2.1 Voltage Regulation

The system uses boost and buck converters for voltage regulation, as shown in Figures 6.2, 6.3, and 6.4. The boost converter uses the LM3478 IC to step up the voltage from the 12V input to 12.6V, which is necessary for charging the battery. The buck converters, utilizing

the LM2596 IC, step down the unregulated input voltage to provide stable outputs of 5V and 3.3V for components such as the Raspberry Pi and ESP32. The schematics for these voltage regulators were designed using WEBENCH-CIRCUIT-DESIGNER from Texas Instruments

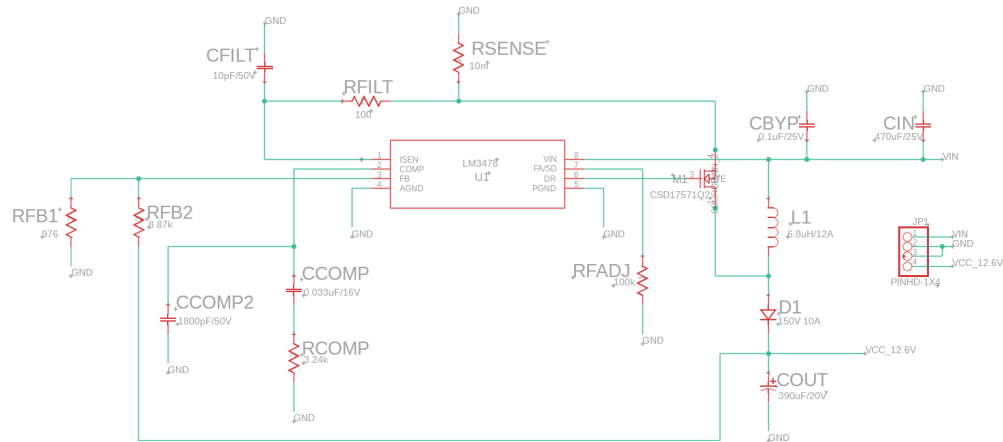


Figure 6.2: 12.6V Boost Converter Schematic
by Authors

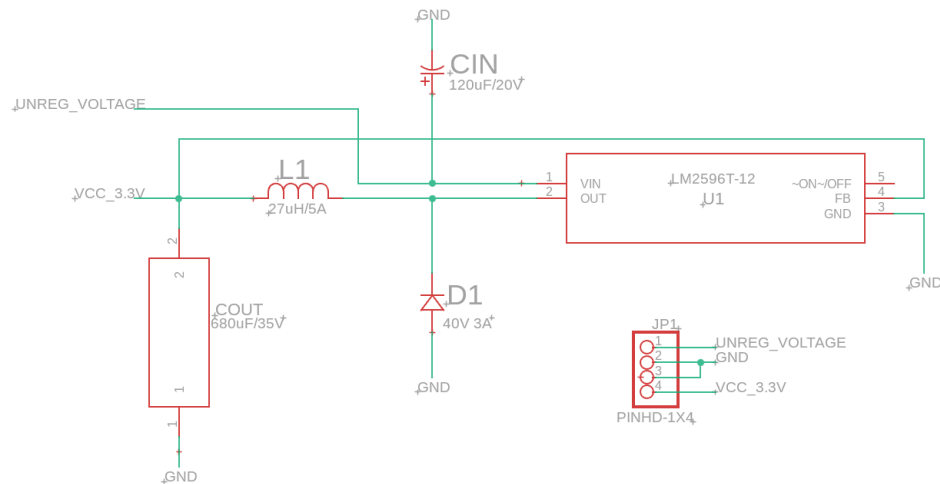


Figure 6.3: 3.3V Buck Converter Schematic
by Authors

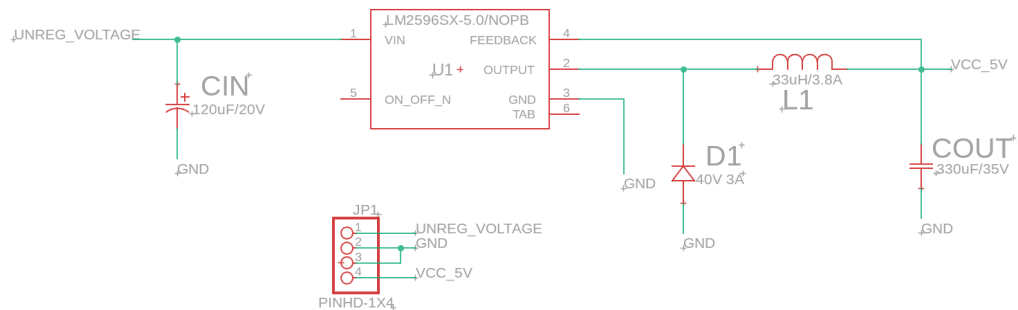


Figure 6.4: 5V Buck Converter Schematic
by Authors

6.2.2 Power Control System

The PowerPath Controller, using the LTC4412 IC, manages the power flow between the primary power source and the backup battery. The schematic for this circuit (Figure 6.5) was designed based on the LTC4412 datasheet, with components chosen to meet the system's specifications. A key component in the design is the P-Channel MOSFET (30V, 5A), which controls the switching between the primary source and the backup battery. This MOSFET ensures that the system draws power from the most suitable source at any given time. The schematic shows how the PowerPath Controller is integrated into the system.

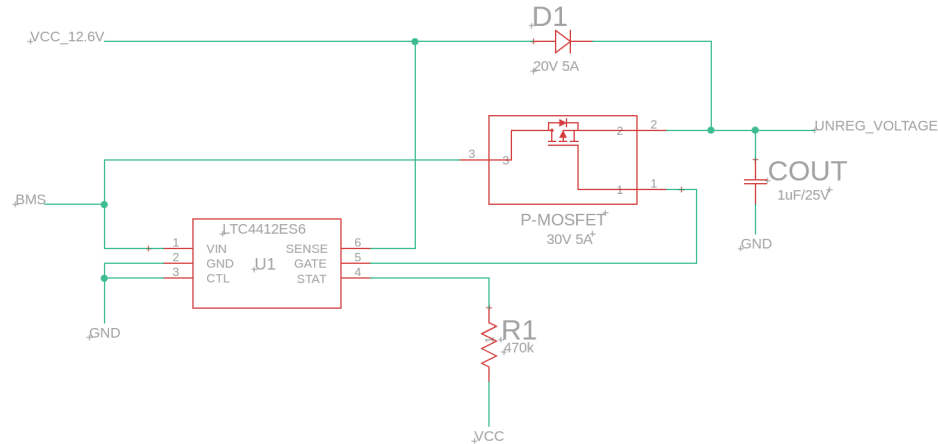


Figure 6.5: PowerPath Controller Schematic
by Authors

The Charger Controller, using the BQ24130 IC, manages the battery charging process. The schematic for this component (Figure 6.6) is based on the reference from the BQ24130 datasheet, showing how it works with the Battery Management System (BMS) to control the charging voltage and current. The P-MOSFET on the right side of the schematic, used in the Charger Controller, is the same as the one in the PowerPath Controller schematic. In the overall system schematic (Figure 6.10), both the PowerPath Controller and Charger Controller circuits are shown utilizing this shared P-MOSFET.

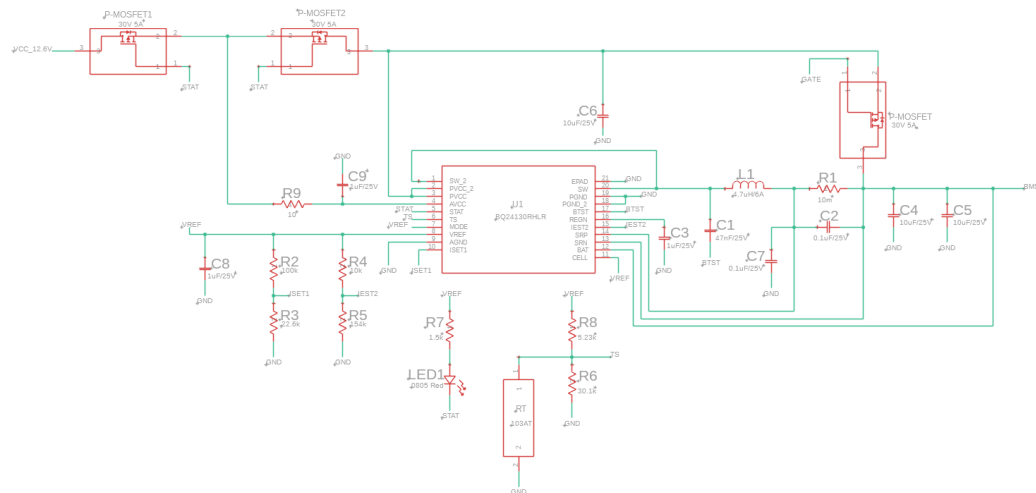
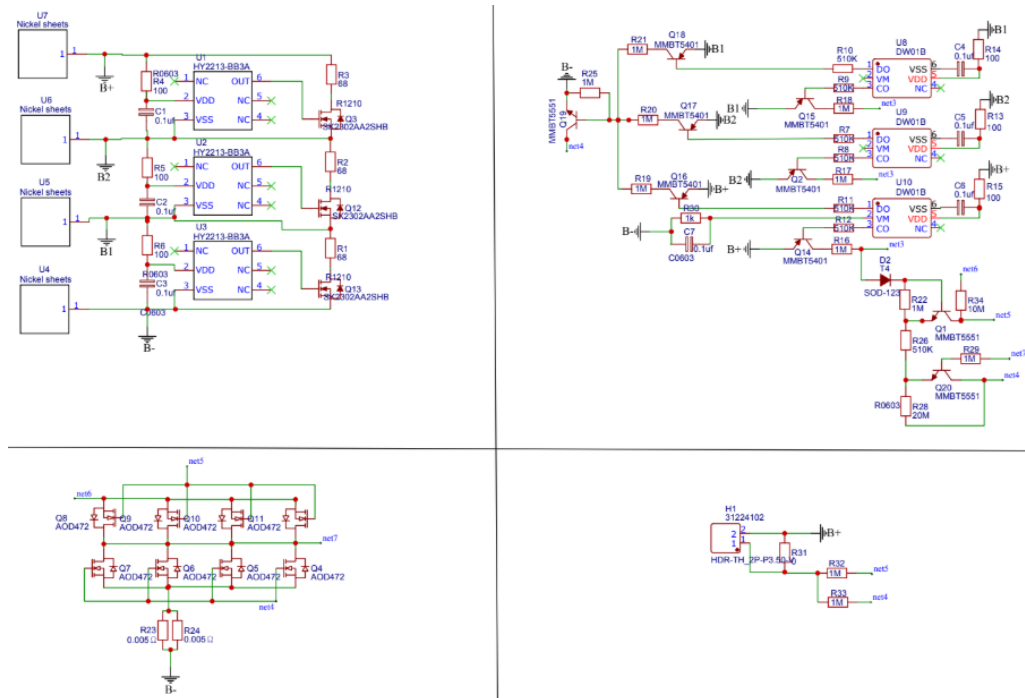


Figure 6.6: Charger Controller Schematic
by Authors

For the Battery Management System (BMS), we are using the HX-3S-FL25A-A board, which will be purchased as an assembled unit rather than designed from scratch. Since the BMS is the only part of the system that we will not be designing ourselves, the schematic for this component (Figure 6.7) was sourced from a project shared by the user "Oleg Oleg" on pcbway.com. This schematic shows the connections for the BMS board. In the overall system schematic (Figure 6.10), the connection to the BMS is shown with its connections to the PowerPath Controller and Charger Controller, demonstrating how it fits into the overall power management system.



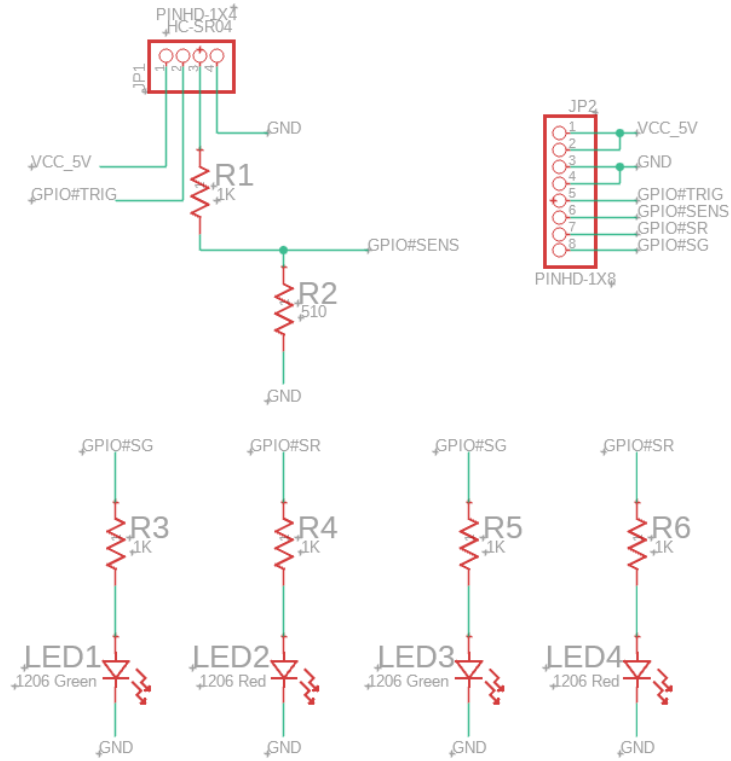


Figure 6.8: Sensors Schematic
by Authors

6.2.4 MCU

The schematic for the ESP32-S3-WROOM-1-N8R8 (Figure 6.9) was designed using the reference from the schematic provided by espressif.com. This schematic shows all the essential connections for the ESP32 microcontroller, which serves as the central control unit for the system. It includes connections for power, communication interfaces, GPIO pins, and other necessary components for proper integration.

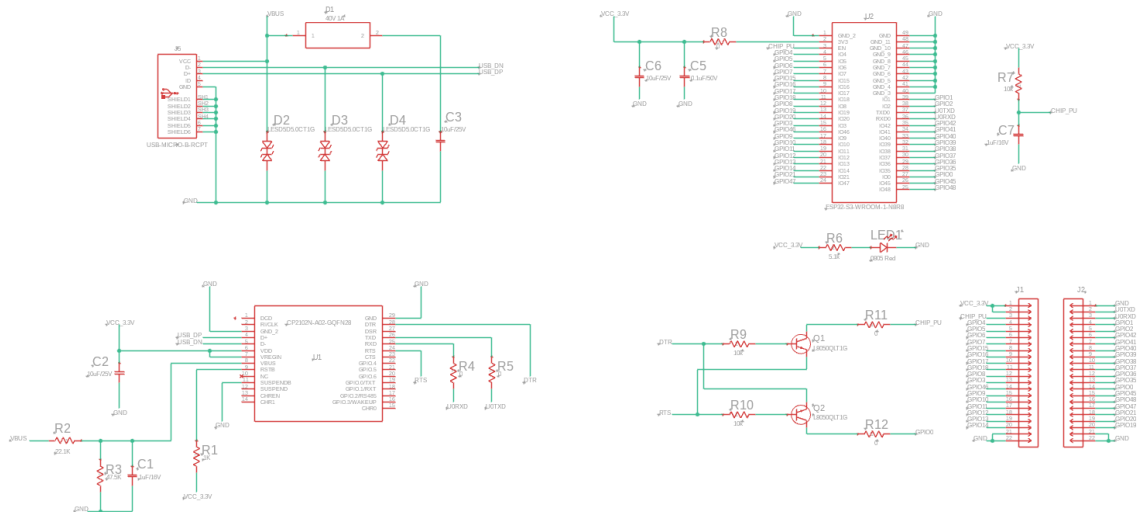


Figure 6.9: ESP32 Schematic

https://dl.espressif.com/dl/schematics/SCH_ESP32-S3-DevKitC-1_V1.1_20221130.pdf

The Overall System Schematic (Figure 6.10) provides a comprehensive view of all the connections within the system, detailing how each component is interconnected. This schematic represents the design of the main PCB, which will serve as the central platform where all other removable PCBs, such as the voltage regulators and ESP32, will be connected. It includes the connections for the Power Supply, PowerPath Controller, Charger Controller, BMS, and MCU, as well as the ultrasonic sensors, LEDs, and Raspberry Pi units. This setup ensures that all components are efficiently connected.

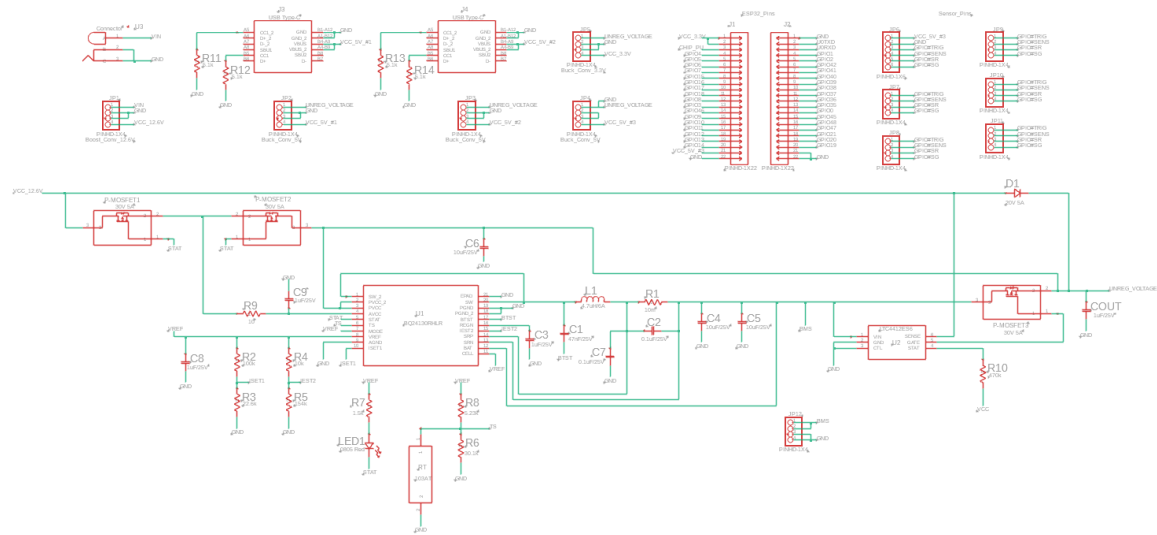


Figure 6.10: Overall System Schematic by Authors

Chapter 7 - System Software Design

For our system's software, we need to both code the ESP32 system with the ultrasonic sensors and LEDS, as well as the Raspberry Pi system with the camera. The overall system diagram shows how the entire system will work with each other.

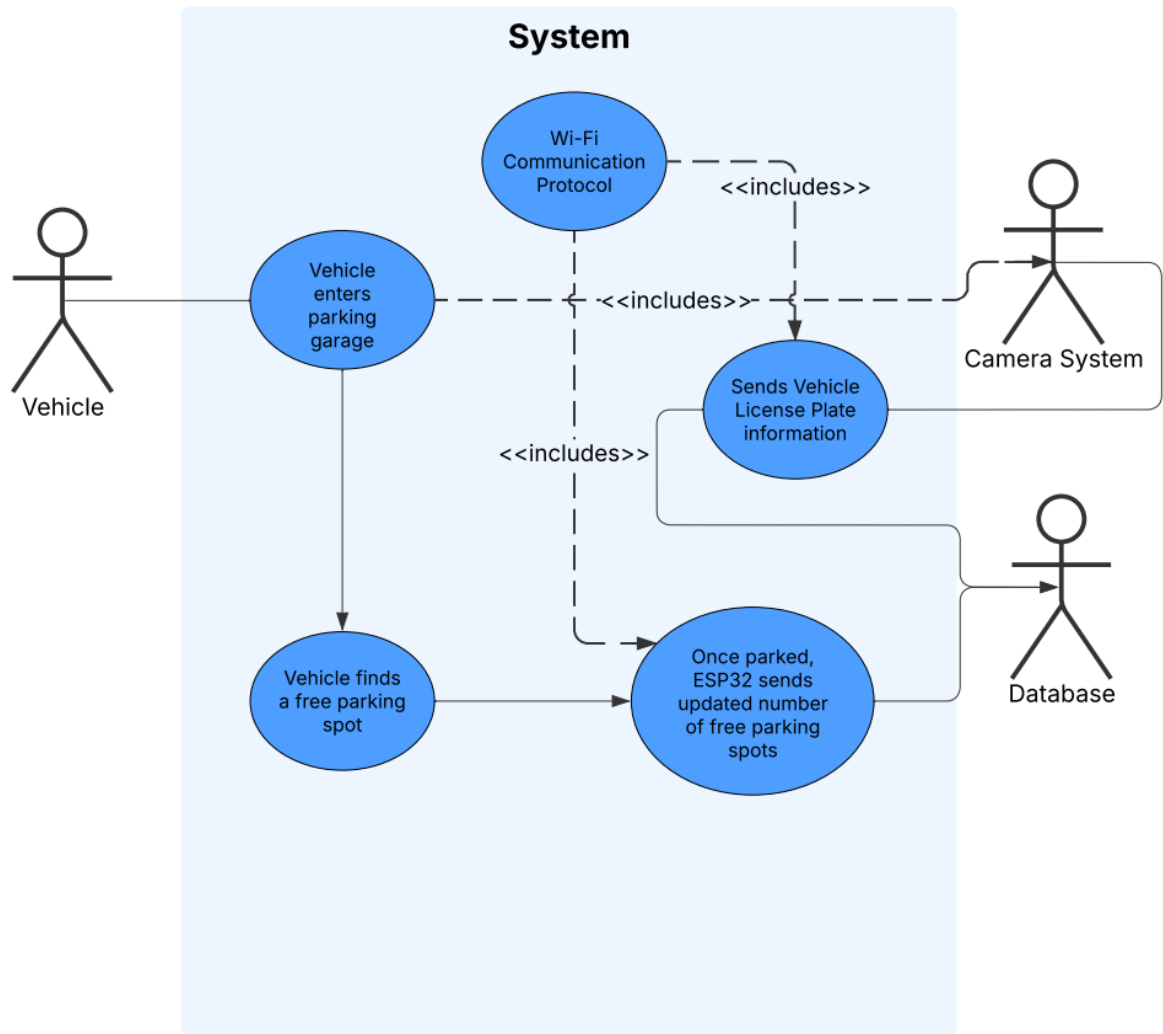


Figure 7.1: Software Use Case Diagram
by Authors

Chapter 10 - Administrative Content

Chapter 10 includes an overview of our project, ranging from a budget for the project to some timelines as well. The first section of this chapter talks about our budget and how we chose to allocate some money for each part of the project, as well as including a bill for materials for those parts we used. The second section shows how we distributed the work for each member. The last section talks about our project's timeline and when we were able to do certain tasks.

10.1 Budget and Financing

For our budget, we have given estimates that should be relatively close to how much we will be spending on our project. Since it is our own project and not sponsored, the team will be the ones using their money to buy the items, so it will be split up accordingly.

Table 10.1.1: Budget Allocation

Sub-System	Budget (USD)
Power (Batteries)	\$ 50.00
Sensors and Processing	\$ 200.00
PCBs and Electrical	\$ 100.00
Miscellaneous	\$ 50.00
Total	\$ 400

Table 10.1.2: 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	Sensors and Processing	3	\$3.50	\$10.50
Raspberry Pi	Sensors and Processing	2	\$61.99	\$123.98
Singnage Displays	Sensors and Processing	2	\$1.59	\$3.18
Power Supply Adapter	Power (Batteries)	1	\$15.99	\$15.99
Batteries	Power (Batteries)	8	\$1.95	\$15.60
Voltage Regulators	PCBs and Electrical	4	\$3.99	\$15.96

PCB for Sensors, Singnage Display	PCBs and Electrical	2	\$1.59	\$3.18
PCB for BMS	PCBs and Electrical	1	\$4.99	\$4.99
Miscellaneous Components	Miscellaneous	1	\$50	\$50.00
Total				\$294.46

10.2 Work Distribution

From our hardware and software diagrams, we will split the workloads between each member. Since Mark is the only EE in our group, he will focus on the PCB with most components while Chris and Tony will work on the software portion as well as helping with the cameras.

Table 10.2.1: Members' Responsibilities

Electrical Engineering	Responsibilities
Mark Rehn	PCB design
	PSU design
	MCU communications
Computer Engineering	Responsibilities
Chris Najem	Software for cameras
	Raspberry Pi communication with camera
	Software to help antenna communication
Computer Engineering	Responsibilities
Tony Mai	MCU connection with Display
	MCU connection with ultrasonic sensor/LED
	Software for ultrasonic sensor and LED

10.3 Project Milestones

During the formation of our group, we gave an estimate as to how often we will meet and work on our project. We then went based off our estimates and created the tables below for our expected timelines:

Table 10.3.1: Project Documentation

Project Documentation				
Item	Start Date	End Date	Duration	Description
Group Formation	01/07/2025	01/14/2025	1 week	Chris Najem, Mark Rehn, and Tony Mai
Brainstorming	01/14/2025	01/17/2025	0.5 week	Discuss and select the best idea

Initial Document	01/17/2025	01/24/2025	1 week	Divide and Conquer (10 pages)
Group Website	01/24/2025	02/07/2025	2 weeks	Update and upload D&C report
Midterm Document	02/10/2025	03/24/2025	6 weeks	Midterm Document (60 pages)
Update Group Website	03/28/2025	04/04/2025	1 week	Update and upload midterm report
Final Document	03/24/2025	04/22/2025	4 weeks	Final Document (90 pages)

Table 10.3.2: Project Fabrication

Project Fabrication				
Item	Start Date	End Date	Duration	Description
Components Selection	01/17/2025	02/07/2025	3 weeks	Choose project components
System Design	02/07/2025	02/28/2025	3 weeks	Create system schematics
Breadboard Prototype	02/21/2025	03/21/2025	4 weeks	Build and test initial prototype
System Testing	02/28/2025	03/21/2025	3 weeks	Verify system functionality
PCB Design	03/21/2025	04/11/2025	3 weeks	Design PCB layout
PCB Testing	TBD	TBD	TBD	Test manufactured PCB
Final Prototype	TBD	TBD	TBD	Assemble and finalize system