Design and Implementation of a Smart Vertical Parking System.

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Submitted to:

THE DEPARTMENT OF MECHANICAL ENGINEERING
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ABSTRACT

Due to rapid urbanization and increasing vehicle ownership, parking space scarcity has become a major problem in modern cities. Conventional parking systems require large horizontal spaces, which are often unavailable in densely populated areas. Automated and robotic parking systems offer an effective solution by utilizing vertical space efficiently.

This project presents the design and development of a **DIY robotic parking system** that demonstrates a vertical parking mechanism using a belt and pulley lifting system. The system is conceptually designed to handle real-life vehicle loads, while a scaled prototype using toy cars is developed for demonstration purposes. An **Arduino Mega microcontroller** is used as the central control unit, integrated with **RFID-based access control**, **IR sensors for slot detection**, and an **LCD display for system status**.

The developed prototype successfully demonstrates automated parking and retrieval operations. The proposed system provides a cost-effective, scalable, and space-efficient solution for future smart parking applications.

LIST OF ABBREVIATIONS

Abbreviation	Full Form
APS	Automated Parking System
AGV	Automated Guided Vehicle
DIY	Do It Yourself
RFID	Radio Frequency Identification
IR	Infrared
LCD	Liquid Crystal Display
MCU	Microcontroller Unit
PLC	Programmable Logic Controller
AC	Alternating Current
DC	Direct Current
IoT	Internet of Things
AI	Artificial Intelligence
CAD	Computer-Aided Design
PSU	Power Supply Unit
I/O	Input / Output
GPS	Global Positioning System
NEMA	National Electrical Manufacturers Association
3D	Three-Dimensional
V	Volt
A	Ampere
Kg	Kilogram
N	Newton
Nm	Newton-meter
Hz	Hertz
RPM	Revolutions Per Minute

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CHAPTER 1: INTRODUCTION

1.1 Background of the Study

The rapid growth of urbanization across the world has led to a significant increase in vehicle ownership. With rising population density and economic development, private vehicles have become a primary mode of transportation in many cities. However, urban land availability has not expanded at the same rate as vehicle growth, creating severe parking challenges.

In densely populated cities, limited land resources make it difficult to allocate sufficient space for conventional parking facilities. As a result, improper roadside parking has become common, leading to traffic congestion, reduced road safety, and inefficient use of public space. This imbalance between increasing vehicle numbers and limited urban space highlights the urgent need for alternative parking solutions.

Automated and robotic parking systems have emerged as an effective approach to address this issue by utilizing vertical space instead of horizontal land. Such systems can significantly increase parking capacity while reducing land requirements, making them suitable for urban environments.

1.2 Problem Statement

Conventional parking systems primarily rely on horizontal layouts, which require large areas of land. In urban regions, the high cost of land acquisition makes horizontal parking economically inefficient and often impractical. Multi-store commercial parking systems are available, but their installation and maintenance costs are significantly high, limiting their accessibility to large commercial developers.

Additionally, most commercially available automated parking systems involve complex mechanical structures, industrial-grade controllers, and expensive components. These factors make them unsuitable for homeowners, small residential buildings, and small businesses that require affordable parking solutions.

Therefore, there is a need for a **low-cost, efficient, and scalable parking system** that can be implemented with minimal space and reduced financial investment while still demonstrating the benefits of automation and vertical parking.

1.3 Objectives of the Project

The main objectives of this project are as follows:

- ✓ To design and develop a **low-cost DIY robotic parking system**.
- ✓ To demonstrate efficient utilization of **vertical space** for parking.
- ✓ To design a system that is **scalable** and can be expanded by adding more parking levels or slots.
- ✓ To integrate basic automation using a microcontroller-based control system.
- ✓ To develop a functional prototype that demonstrates automated parking and retrieval operations.

1.4 Scope and Limitations

The scope of this project includes the design, fabrication, and testing of a **scaled prototype** of a robotic parking system. The prototype is designed to demonstrate the working principle of a vertical parking mechanism using a limited number of parking slots.

Scope of the Project

- ➢ Prototype supports **two vertical levels** with a total of **eight parking slots**.
- ➢ Automation is implemented using a microcontroller-based system.
- ➢ Conceptual design considers **real-life vehicle weight**, while physical testing uses toy cars.

Limitations of the Project

- ➢ The prototype cannot physically support real vehicle loads.
- ➢ Industrial safety features such as fire detection and emergency braking are not implemented.
- ➢ The system is intended for demonstration and academic purposes, not immediate commercial deployment.

1.5 Significance of the Study

This study is significant as it presents an affordable and practical alternative to expensive commercial parking systems. The proposed DIY robotic parking system demonstrates how automation and vertical space utilization can be achieved using low-cost components.

The project is particularly beneficial for **homeowners, small residential buildings, and small businesses** that face parking challenges but cannot afford high-end automated parking solutions. Additionally, this study provides valuable insight into the integration of mechanical design, electronics, and automation, contributing to academic research and future development of smart parking systems.

CHAPTER 2: LITERATURE REVIEW

2.1 History of Automated Parking Systems (APS)

Automated Parking Systems (APS) were developed to address the increasing demand for parking space in urban areas where land availability is limited. The concept of automated parking dates back to the early twentieth century, when mechanical systems were introduced to reduce manual effort and improve space utilization.

One of the earliest forms of automated parking was the **rotary parking system**, commonly referred to as a carousel system. These systems operated using simple mechanical rotation, where vehicles were lifted and rotated vertically similar to a Ferris wheel. Although mechanically simple, early rotary systems had limitations such as low capacity, slow operation, and limited vehicle size accommodation.

As urbanization increased, more advanced systems were developed, including **stack-based parking systems** that allowed vehicles to be parked in multiple vertical levels. These systems improved space efficiency but still required manual vehicle handling.

In recent decades, advancements in automation, sensors, and control technology have led to the development of **puzzle-type automated parking systems**. These systems use a combination of vertical and horizontal movements to rearrange parking pallets dynamically, allowing efficient storage and retrieval of vehicles. Modern APS systems incorporate microcontrollers, programmable logic controllers (PLCs), and sensor-based feedback to improve reliability, safety, and efficiency.

1905 – Paris, France: One of the first automated parking systems appeared at Garage Rue de Ponthieu, using a mechanical elevator to move cars between levels. This system aimed to optimize space in tight urban contexts. **(Wikipedia) (1)**

1920s – Paternoster Systems: In both Europe and the U.S., paternoster-style vertical car elevators emerged, resembling a Ferris wheel and enabling around eight vehicles to rotate vertically in the footprint usually needed for two cars. These systems were mechanically simple and popular because they maximized vertical space utilization. The Trivial Company +1 **(2)**

1940s: O.A. Light attempted early vertical parking units that could vertically stack three cars per side, influencing later APS designs. E.W. Austin invented automated garage systems that dominated APS innovation between the 1940s–60s with designs like “Bowser,” “Pigeon Hole,” and “Roto Park.” **(3)**

1960s – Auto Stacker (UK): This ambitious automated multi-store parking project in Woolwich, London, used conveyor belts and lifts to distribute cars within 256 spaces. However, it failed to operate reliably and was demolished by the mid-1960s. **Wikipedia (3)**

Mid-1960s – Vertical-Parking System: Invented by Bob Lichti, this Ferris wheel–like system could hold about 22 vehicles, exemplifying an evolution toward more complex vertical solutions. **(4)**

Vertical Car Parking System — Rakhmeen Gul et al. A prototype and design of a rotary vertical parking system showing automation and space efficiency. **Research Gate (5)**

Multilevel Automated Car Parking System — Anisur Rahman, Sk. Md. Golam Mostafa, Md. Shaikot Alam Shakil, Masud Hasan Journal of Advanced Research in Dynamical and Control Systems (2020), focuses on multilevel automated parking using mechanical and sensor systems. **Research Gate (6)**

Reachable Set-based Path Planning for Automated Vertical Parking System — In Hyuk Oh, Ju Won Seo, Jin Sung Kim & Chung Choo Chung (2023) Path planning methods specific to automated vertical parking scenarios. **(7)**

A multi-step vertical parking path planning algorithm (Whale Optimization Algorithm); relevant for intelligent APS design. ACM Digital Library Design and Development of a Low-Cost Automated Parking System — Joy Bhowmik (Independent University Bangladesh, 2023) **(8)**

SMART Vertical Rotary Car Parking System Detailed design characteristics of rotary vertical parking with mechanisms and IoT integration. IJSREM (2022) **(9)**

Advanced Mechanised Car Parking System — K. Durgaprasad, Y. Vikas Krishna, Ch. Mohan Sai Manikanta (IJERT, 2021) **(10)**

Online Operations Strategies for Automated Multistory Parking Facilities — Transportation Research Part E (2021) **(11)**

Automatic Multi-Level Car Parking System — Mahima R, Meghashree M D, Pallavi G, Rachana D Nayaka (2018) **(12)**

A practical automatic multi-level car parking design paper with implementations and IR sensor control. IJRESCIT **(13)**

Fuzzy Logic Based Autonomous Parking Systems — Part I & II — Yu Wang & Xiaoxi Zhu. Two papers on intelligent parking control using fuzzy logic, relevant for automation control theory. **(14)**

IoT-Enabled Smart Car Parking System — Abdullah Al Mamun et al. (2024). A modern IoT integrated automated parking management research. **(15)**

by H Al-Kharusi · 2014 · Cited by 1 — An Image Processing Technique is used to implement an **intelligent car parking management system** at the Massey University car park. Intelligent Car Parking Management System — Hilal Al-Kharusi (2014 Thesis) **(16)**

Continued Innovation:

By 1964, automated parking management systems were being developed with valet and elevator integration similar to modern APS configurations.

While interest fluctuated in parts of the U.S., Japan built tens of thousands of APS spaces in the 1970s–90s as land became more constrained. By 2012, APS installations in Japan reached around 1.6 million parking spaces.

Modern APS

Today's vertical automated parking systems include fully automatic tower, rotary, puzzle, and cart type solutions that leverage elevators, robotics, and control systems to stack and retrieve vehicles with little to no human intervention. These systems are widely adopted in Asia, Europe, and Central America to solve urban parking shortages and reduce surface footprint.

2.2 Types of Vertical Parking Systems

Vertical parking systems are designed to maximize parking capacity by utilizing vertical space. Based on mechanical structure and operational method, vertical parking systems can be classified into the following types:

2.2.1 Rotary (Carousel) Parking Systems

Rotary parking systems consist of a vertical rotating structure where vehicles are parked on platforms attached to a rotating frame. The system rotates to bring the desired vehicle to ground level.

Advantages:

- ✓ Compact design
- ✓ Simple mechanical structure
- ✓ Low power consumption

Limitations:

- ✓ Limited parking capacity
- ✓ Not suitable for large or heavy vehicles

2.2.2 Stacker-Based Parking Systems

Stacker systems use vertical lifting mechanisms to park vehicles on stacked platforms. These systems can be semi-automatic or fully automatic.

Advantages:

- Better space utilization than rotary systems
- Suitable for residential buildings

Limitations:

- Limited scalability
- Manual intervention often required

2.2.3 Automated Guided Vehicle (AGV) Based Parking Systems

AGV-based parking systems use autonomous robots or shuttles to transport vehicles to designated parking slots. These systems are highly flexible and efficient.

Advantages:

- ✓ High parking density
- ✓ Fast retrieval time
- ✓ Fully automated operation

Limitations:

- ✓ High initial cost
- ✓ Complex control system.

2.3 Review of Mechanical Components Used in Parking Systems:

Mechanical components play a critical role in the performance and reliability of automated parking systems.

2.3.1 Motors

Electric motors provide the driving force for lifting and transferring vehicles. Common motor types used include:

- ✓ DC motors
- ✓ AC induction motors
- ✓ Stepper motors
- ✓ Servo motors
- ✓ Stepper motors are often used in prototype systems due to their precise position control, while AC and servo motors are preferred in industrial applications for higher load capacity.

2.3.2 Gearboxes

Gearboxes are used to increase torque and reduce motor speed. In parking systems, gearboxes ensure smooth lifting and controlled movement under heavy loads. Worm gear and planetary gearboxes are commonly used due to their high torque output.

2.3.3 Lifting Mechanisms

Several lifting mechanisms are used in vertical parking systems, including:

- ✓ Belt and pulley systems
- ✓ Chain and sprocket systems
- ✓ Hydraulic lifting systems

Belt and pulley mechanisms are preferred in low-cost systems due to simplicity and low maintenance, whereas hydraulic systems are used for heavy-duty applications.

2.4 Review of Control Systems Used in Parking Automation

Control systems are responsible for coordinating mechanical movements, sensor feedback, and user interaction.

2.4.1 Arduino-Based Control Systems

Arduino microcontrollers are widely used in academic and prototype-level parking systems. They offer ease of programming, low cost, and compatibility with sensors and actuators.

Applications:

- ➢ Slot detection
- ➢ Motor control
- ➢ Display interfacing

2.4.2 PLC-Based Control Systems

PLCs are commonly used in industrial parking systems due to their reliability and ability to handle multiple inputs and outputs.

Advantages:

- ➢ High reliability
- ➢ Industrial-grade safety

Limitations:

- High cost
- Requires skilled programming

2.4.3 Raspberry Pi-Based Systems

Raspberry Pi is used in advanced parking systems where image processing, networking, or cloud connectivity is required.

Advantages:

- High processing capability
- IoT integration

Limitations:

- Less suitable for real-time motor control

2.5 Comparative Analysis of Existing Parking Solutions

A comparative analysis of existing parking systems highlights the advantages and limitations of different approaches.

Parking System Type	Cost	Space Efficiency	Power Consumption
Conventional Parking	Low	Very Low	Low
Rotary Parking	Medium	Medium	Low
Stacker Parking	Medium	High	Medium
AGV-Based Parking	High	Very High	High
DIY Robotic Parking (Proposed)	Low	High	Low

From the comparison, it is evident that low-cost automated parking solutions can provide a balance between space efficiency and energy consumption. The proposed DIY robotic parking system focuses on affordability and simplicity while maintaining efficient vertical space utilization.

2.6 Summary

This chapter reviewed the historical development of automated parking systems, types of vertical parking mechanisms, mechanical components, control systems, and a comparative analysis of existing solutions. The review highlights the need for a low-cost, scalable, and efficient robotic parking system, which forms the basis of the proposed project.

CHAPTER 3: METHODOLOGY

3.1 Research Framework

The research framework of this project is developed to systematically design, analyze, and implement a DIY robotic parking system that is low-cost, space-efficient, and scalable. The methodology follows a structured engineering approach to ensure that the final prototype meets functional, mechanical, and safety requirements.

The first stage of the research framework involves **problem identification**. Rapid urbanization and increased vehicle ownership have created parking challenges, particularly for residential buildings and small commercial facilities. Existing commercial automated parking systems are costly and complex, making them inaccessible to small-scale users. This problem formed the foundation of the research.

The second stage involves an extensive **literature review** to understand existing automated parking systems, their mechanical structures, control methods, and limitations. This review helped identify suitable mechanisms and technologies that could be adapted for a low-cost DIY solution.

In the third stage, **conceptual design development** was carried out. Various parking layouts and lifting mechanisms were evaluated, such as rotary systems, hydraulic lifts, and belt-driven systems. Based on simplicity, cost, and ease of fabrication, a belt and pulley-based vertical parking mechanism was selected.

The fourth stage involves **component selection and system design**. Mechanical components such as motors, belts, pulleys, and structural materials were selected based on availability, load-handling capability, and compatibility. Simultaneously, electronic components including microcontrollers, sensors, and motor drivers were chosen to ensure smooth automation.

The final stages of the research framework include **prototype fabrication**, **testing**, and **performance evaluation**. The prototype was tested under different operating conditions to observe system behavior, identify errors, and improve reliability. This step-by-step framework ensures a logical and systematic progression from concept to implementation.

3.2 Design Requirements

Design requirements define the functional and physical constraints within which the robotic parking system must operate. These requirements ensure system reliability, safety, and practical usability.

3.2.1 Load Capacity Requirement

The robotic parking system is conceptually designed to handle the load of a real-life passenger vehicle. An average passenger car weight is considered during the design phase to ensure realistic mechanical analysis. Although the physical prototype uses toy cars for demonstration, the design calculations are performed assuming actual vehicle weight.

Considering real-life load conditions allows the system to be theoretically scalable. This approach ensures that mechanical components such as motors, belts, and structural elements are selected with sufficient strength and reliability.

3.2.2 Safety Factor Consideration

Safety factors are an essential part of mechanical system design. In this project, safety factors are incorporated to account for uncertainties such as dynamic loading, sudden load variations, material imperfections, and wear over time. The safety factor ensures that the system can withstand loads higher than the calculated design load without failure. This is particularly important for lifting mechanisms, where failure could result in severe damage or safety hazards.3.2.3 Dimensional and Structural Requirements

The dimensions of the prototype are selected based on laboratory constraints and ease of demonstration. The system consists of two vertical levels with multiple parking slots arranged symmetrically to maintain balance.

The vertical spacing between levels is carefully determined to allow sufficient clearance for vehicle movement and pallet operation. Structural rigidity is ensured to prevent misalignment during lifting operations.

3.3 Data Collection and Design Calculations

Unlike experimental research, this project relies heavily on **analytical data collection** through mechanical calculations and engineering assumptions. Data collection focuses on parameters necessary for designing a safe and functional lifting system.

Key parameters collected include:

- ✓ Estimated vehicle weight
- ✓ Gravitational force
- ✓ Pulley radius
- ✓ Belt material properties
- ✓ Motor torque ratings

Using these parameters, the **required lifting force** and **motor torque** are calculated. The torque calculation ensures that the selected motor can lift the load smoothly without stalling.

Material strength data such as tensile strength and allowable stress are also considered while selecting belts and structural elements. These calculations ensure that the system operates within safe stress limits. All calculation results are documented and later verified through practical testing. Detailed torque and strength calculations are presented separately in the design analysis chapter to maintain clarity.

3.4 Software Tools Used

Software tools play a vital role in modern engineering design by reducing errors and improving accuracy.3.4.1 Computer-Aided Design (CAD) Software

CAD software such as **SolidWorks** and **AutoCAD** are used extensively during the design phase. These tools are used to create detailed two-dimensional drawings and three-dimensional models of the robotic parking system.

The CAD models help visualize component placement, check alignment, and identify potential interference between moving parts. This step significantly reduces fabrication errors and improves design efficiency.

3.4.2 Simulation and Design Verification Tools

Basic simulation tools within the CAD software are used to analyze motion paths, interference, and load distribution. Motion simulations help verify smooth vertical movement of pallets and proper functioning of the belt and pulley system.

Simulation results provide confidence in the mechanical design before physical fabrication. This approach reduces material wastage and saves development time.

3.5 Summary

This chapter presented a comprehensive explanation of the methodology followed in developing the DIY robotic parking system. The research framework, design requirements, data collection methods, and software tools were discussed in detail. The systematic approach ensures that the design is mechanically sound, safe, and scalable. The next chapter focuses on detailed **design analysis**, including mechanical components, load considerations, and system configuration.

CHAPTER 4: PROTOTYPE DESIGN AND COMPONENTS

4.1 Conceptual Design

The conceptual design phase is the foundation of the proposed DIY robotic parking system. At this stage, the primary focus was to transform the project objectives into a feasible mechanical and electronic system layout. Initial ideas were developed through hand-drawn sketches to visualize the overall structure, vertical arrangement of parking slots, and movement of pallets.

These sketches helped in understanding space requirements, load distribution, and the relative positioning of mechanical and electronic components. Based on these initial sketches, a three-dimensional (3D) model of the system was developed using computer-aided design (CAD) software. The 3D model provided a clear visualization of the vertical parking mechanism, frame structure, pallet arrangement, and lifting system.

The conceptual design ensures that the system can store vehicles in multiple vertical levels while maintaining stability and smooth operation. It also allowed early identification of potential design issues such as misalignment, insufficient clearance, and mechanical interference, which were corrected before prototype fabrication.

Figure 4.1: Conceptual 3D model of the DIY robotic parking system

4.2 Mechanical Components

Mechanical components form the structural backbone of the robotic parking system. They are responsible for supporting loads, guiding movement, and ensuring mechanical stability.

4.2.1 Structural Frame

The structural frame provides overall support to the robotic parking system. The frame is designed to withstand the combined weight of the parking pallets, lifting mechanism, and vehicle load.

For the prototype, lightweight yet rigid materials such as aluminum sections were used to ensure ease of fabrication and portability. In real-life implementation, structural steel is recommended due to its high strength and durability.

The frame is designed with vertical columns and horizontal beams to ensure load distribution and structural balance. Proper bracing is provided to minimize vibration and deflection during lifting operations.

Figure 4.2: Structural frame of the robotic parking system prototype

4.2.2 Lifting Mechanism

The lifting mechanism is a critical part of the robotic parking system. It is responsible for vertical movement of the parking pallets. In this project, a **belt and pulley-based lifting mechanism** is used due to its simplicity, low cost, and ease of maintenance.

Timing belts and timing pulleys are used to ensure synchronized motion and prevent slippage. Stepper motors provide precise control over vertical positioning. The belt-driven system allows smooth and controlled lifting of the pallet.

Although alternative lifting mechanisms such as lead screws, chain drives, and hydraulic systems were considered, the belt and pulley system was selected for the prototype due to lower complexity and cost.

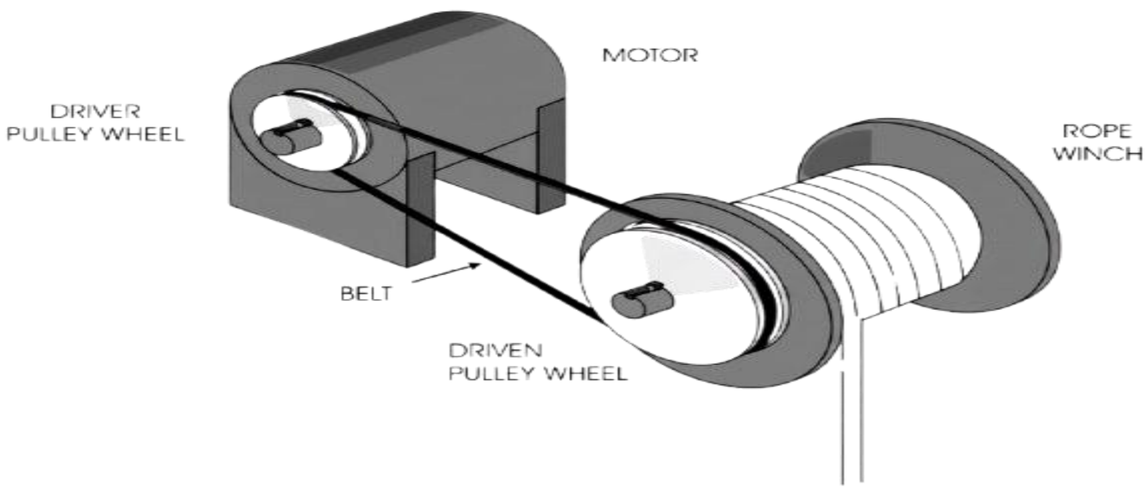

Figure 4.3: Belt and pulley-based lifting mechanism

4.2.3 Pallets and Guide Rails

Pallets are the platforms on which vehicles are parked. In the prototype, pallets are made from acrylic sheets due to their lightweight nature and ease of fabrication. The pallets are designed to support the toy car used for demonstration.

Guide rails are installed along the vertical frame to ensure straight and stable movement of pallets during lifting and lowering operations. These rails prevent lateral movement and ensure alignment throughout operation.

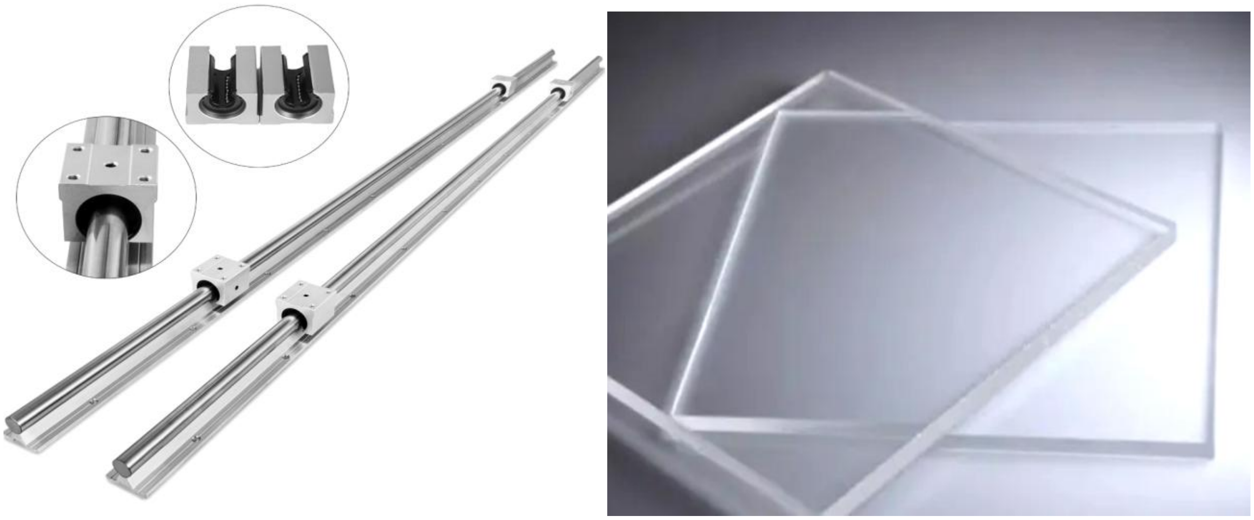

Figure 4.4: Acrylic pallet and guide rail arrangement

4.3 Electronic and Control Components

Electronic components act as the control and automation unit of the robotic parking system. These components coordinate sensing, decision-making, and actuation.

4.3.1 Microcontroller Unit

The central control unit of the system is the **Arduino Mega 2560 R3**. It was selected due to its large number of input/output pins, memory capacity, and compatibility with multiple sensors and actuators.

The microcontroller processes signal from sensors, executes control logic, and generates output signals to motor drivers and actuators.

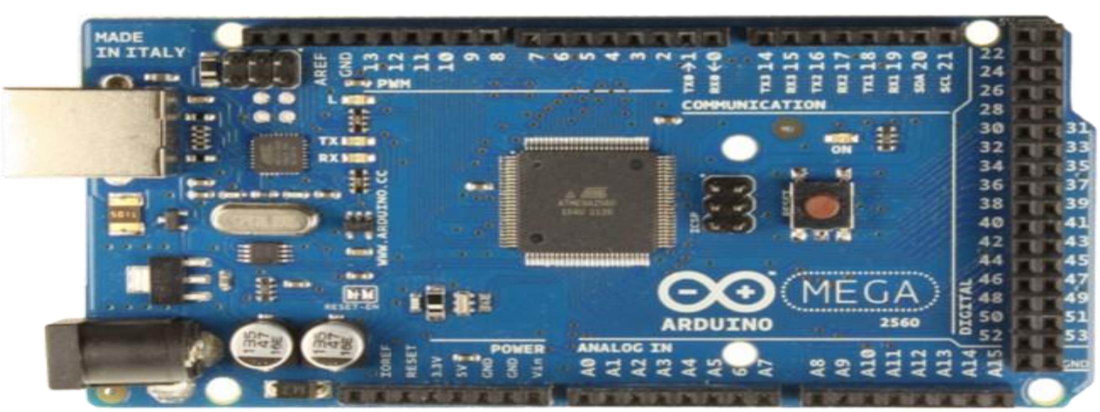

Figure 4.5: Arduino Mega 2560 R3 microcontroller

4.3.2 Sensors

Sensors are used to detect position, slot availability, and movement limits.

- **Infrared Obstacle Avoidance IR Sensor Modules (8 pcs):** Used to detect vehicle presence and slot occupancy.
- **Limit Switches (2 pcs):** Used to define upper and lower limits of pallet movement.

These sensors ensure accurate positioning and safe operation of the system.

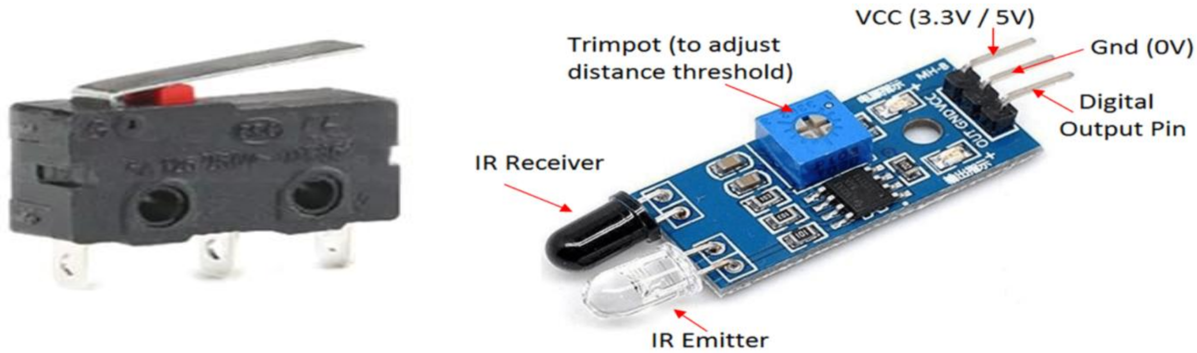

Figure 4.6: Infrared sensor and limit switch used in the system

4.3.3 Actuators

Actuators convert electrical signals into mechanical motion.

- **Stepper Motors (NEMA-17, 2 pcs):** Used for precise vertical lifting.
- **Servo Motor MG995 (360°):** Used for gate or locking mechanism.

Stepper motors are controlled using **DRV8825 stepper motor driver modules**, which allow precise speed and direction control.

Figure 4.7: Stepper motor and servo motor used in the system4.3.4 Display and Identification System

A **20×4 LCD display** with an **I2C LCD driver** is used to display system status, slot availability, and user instructions.

For user identification and access control, an **RFID/NFC module (MFRC522)** and **RFID tags (4 pcs)** are used. This ensures authorized access to the parking system.

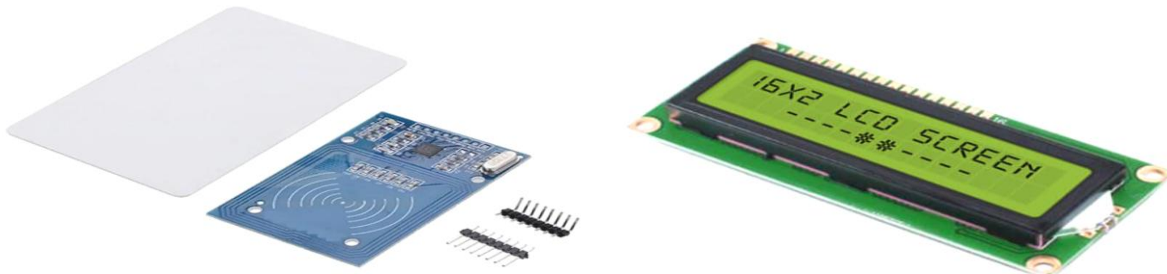

Figure 4.8: LCD display and RFID module

4.3.5 Power Supply and Supporting Components

A **12V, 10A power supply** provides power to motors and control circuitry. Voltage regulation is achieved using **LM7805 voltage regulators** to supply 5V to sensitive components.

Breadboard, jumper wires, and connecting wires are used for circuit prototyping and signal routing.

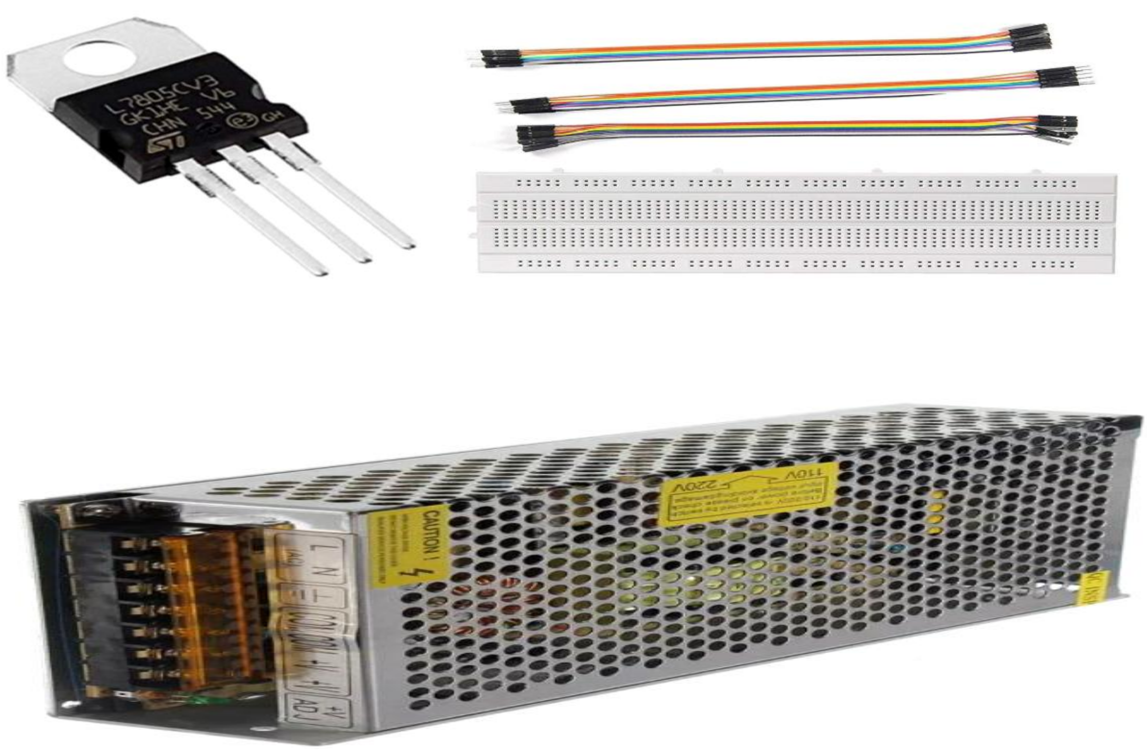

Figure 4.9: Power supply and supporting electronic components

4.4 Circuit Diagram and Logic Flow

The circuit diagram represents the interconnection between the microcontroller, sensors, actuators, and power supply. It acts as the “brain” of the robotic parking system, coordinating all operations.

The logic flow begins with system initialization, followed by sensor input reading. Based on sensor data, the microcontroller determines slot availability and activates the appropriate motors. The lifting mechanism is controlled using stepper motor drivers, while limit switches ensure safe stopping positions.

The logic ensures safe, sequential operation of parking and retrieval processes. Feedback from sensors allows the system to continuously monitor position and status.

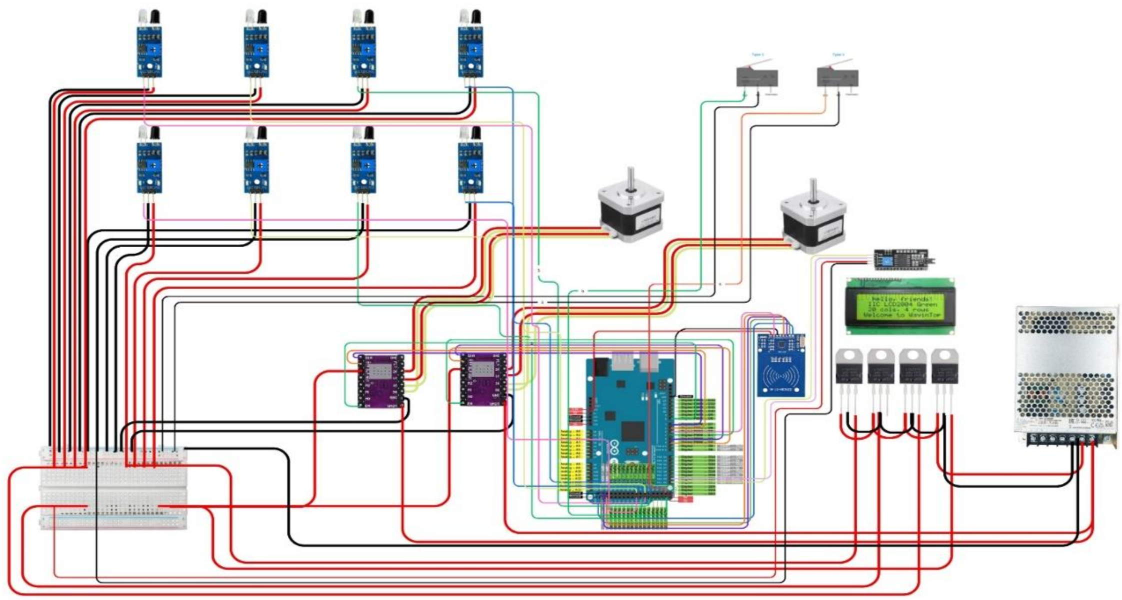

Figure 4.10: Circuit diagram and control logic flow of the system

4.5 Summary

This chapter presented a detailed description of the prototype design and components used in the DIY robotic parking system. The conceptual design, mechanical structure, electronic components, and control logic were discussed comprehensively. All major components used in the project were explained with their roles and functions. The next chapter focuses on **prototype fabrication, assembly, and implementation**.

CHAPTER 5: FABRICATION AND ASSEMBLY

5.1 Material Selection

Material selection is a critical step in the fabrication of the DIY robotic parking system, as it directly affects structural stability, cost, ease of fabrication, and overall system performance. Since the project aims to develop a low-cost prototype, materials were selected based on availability, affordability, strength, and compatibility with DIY fabrication methods.

For the **structural frame**, lightweight materials such as aluminum profiles were selected for the prototype. Aluminum provides sufficient rigidity for supporting the prototype load while being easy to cut, drill, and assemble using basic tools. In a real-life implementation, structural steel would be a more suitable option due to its higher load-bearing capacity and durability.

The **parking pallets** were fabricated using acrylic sheets. Acrylic was chosen due to its lightweight nature, smooth surface finish, and ease of cutting. It also allows clear visibility of the system operation during demonstration.

For the **lifting mechanism**, timing belts and pulleys were selected. Timing belts offer smooth power transmission, minimal slippage, and low maintenance requirements, making them ideal for prototype applications.

Electrical and electronic components such as motors, sensors, and control modules were selected based on compatibility with the Arduino platform, reliability, and ease of integration.5.2 Fabrication Process

The fabrication process involved transforming the conceptual and CAD designs into a physical working prototype. The fabrication process was divided into several stages to ensure accuracy and ease of assembly.

5.2.1 Structural Frame Fabrication

The structural frame components were measured and marked according to the CAD drawings. Aluminum sections were cut using manual cutting tools to achieve the required lengths. Holes were drilled at precise locations to allow bolted connections between frame members.

Bolting was preferred over welding to allow easy disassembly and modification during testing. The vertical columns and horizontal beams were assembled first, followed by cross-bracing to improve structural rigidity.

5.2.2 Pallet Fabrication

Acrylic sheets were cut to form parking pallets using hand tools. The edges were smoothed to prevent friction and ensure smooth sliding along guide rails. Mounting points were created on the pallets to attach the lifting mechanism securely.

5.2.3 Lifting Mechanism Assembly

Timing pulleys were mounted on the stepper motor shafts and aligned carefully to avoid belt misalignment. Timing belts were installed and tensioned properly to ensure smooth vertical motion. Proper belt tension was maintained to prevent slippage and excessive wear.

5.2.4 Electronics Preparation

Electronic components were assembled on a breadboard for initial testing. Motor drivers, sensors, and display modules were connected to the Arduino Mega. Once verified, components were securely mounted onto the prototype frame.

5.3 Integration of Mechanical and Electronic Systems

Integration is the stage where mechanical and electronic subsystems are combined into a single functional unit. The Arduino Mega was mounted at a protected location on the frame to minimize vibration and accidental damage.

Wiring was routed neatly along the frame using cable ties to avoid interference with moving components. Sensors were placed strategically to detect pallet position and slot availability. Limit switches were installed at extreme positions to prevent over-travel of the lifting mechanism.

Motor drivers were positioned close to stepper motors to minimize signal loss. Power supply units were mounted securely to provide stable voltage to all components.

This careful integration ensured reliable communication between mechanical and electronic components, resulting in smooth system operation.

5.4 Challenges in Fabrication and Assembly

During fabrication and assembly, several challenges were encountered, which provided valuable practical learning experience.

5.4.1 Alignment Issues

Initial assembly revealed misalignment between guide rails and pallets, causing uneven motion. This issue was resolved by adjusting mounting positions and using spacers to ensure parallel alignment.

5.4.2 Friction and Motion Resistance

Excessive friction was observed during vertical motion due to surface roughness. This was minimized by smoothing acrylic edges and applying light lubrication to guide rails.

5.4.3 Belt Tension Adjustment

Improper belt tension initially caused slippage. This was resolved by readjusting pulley positions and ensuring optimal belt tension.

5.4.4 Electrical Noise and Wiring Issues

Signal interference occurred due to improper wire routing. This was corrected by separating power and signal wires and securing all connections properly.

5.5 Final Assembly

After resolving fabrication challenges, all components were assembled into the final prototype. The completed system demonstrated smooth parking and retrieval operations with proper sensor feedback and motor control.

Figure 5.1: Final assembled prototype of the DIY robotic parking system

5.6 Summary

This chapter presented a detailed explanation of material selection, fabrication procedures, system integration, and challenges faced during assembly. The successful fabrication and assembly of the prototype validated the design approach and prepared the system for testing and performance evaluation discussed in the next chapter.

CHAPTER 6: TESTING, RESULTS, AND REAL-LIFE COMPARISON

6.1 Performance Testing

Performance testing was conducted to evaluate the operational reliability, efficiency, and accuracy of the DIY robotic parking system prototype. Since the system is designed as a scaled model, testing focused on functional performance rather than full-load stress testing. The tests were carried out under controlled laboratory conditions.

Table 6.1: Space Comparison of Parking Systems in Bangladesh

Parking System Type	Area Required per Car (m^2)	Area for 8 Cars (m^2)
Conventional surface parking	40–45	320–360
Multi-store ramp parking	30–35	240–280
Proposed DIY vertical parking	**12–15**	**96–120**

From Table 6.1, it is evident that the proposed vertical parking system can reduce land usage by approximately **65–70%** compared to conventional parking systems. This space-saving advantage makes the system highly suitable for Bangladesh’s urban environment, particularly for small residential and commercial buildings.

6.1.1 Speed of Parking and Retrieval

The speed of parking and retrieval is a critical performance parameter, as it directly affects user convenience. Multiple test runs were conducted to measure the time required for parking and retrieving a vehicle.

The retrieval time was measured from the moment a user initiates the command using RFID authentication to the point where the vehicle is presented at ground level. The results indicated consistent operation with minimal variation between cycles. Although the prototype operates at a slower speed for safety and demonstration purposes, the system demonstrates predictable and smooth motion.

6.1.2 Load-Bearing Test

Load-bearing tests were conducted using toy vehicles to validate the mechanical stability of the prototype. The pallets were observed under repeated lifting cycles to check for deflection, misalignment, or mechanical failure.

Although the prototype does not physically carry real vehicle loads, the lifting mechanism demonstrated stable performance under the applied load. Conceptual load calculations.

6.1.3 Sensor Accuracy and Reliability

Sensor accuracy is vital for safe and automated operation. Infrared sensors were tested for slot detection accuracy by repeatedly placing and removing vehicles from parking slots. Limit switches were tested to ensure accurate detection of extreme positions.

The sensors consistently detected vehicle presence and pallet position with high reliability. Minor calibration adjustments were required during initial testing, after which sensor performance remained stable.

6.2 Real-Life Comparison

To evaluate the practical relevance of the DIY robotic parking system, a comparison was made with conventional and commercial automated parking systems.

6.2 Bangladesh Case Study: Real-Life Implementation Analysis

Table 6.2: Cost Comparison of Parking Systems

Parking System	Approximate Cost per Car (BDT)
Imported automated parking system	30–60 lakh
Semi-automatic stack parking	20–30 lakh
Proposed DIY vertical parking system	**5–7 lakh**

The proposed system offers a cost reduction of approximately **75–85%** compared to imported automated parking solutions, making it economically viable for Bangladesh.

6.2.1 Urban Parking Scenario in Bangladesh

Bangladesh is experiencing rapid urbanization, particularly in major cities such as Dhaka, Chattogram, Narayanganj, Gazipur, and Sylhet. The continuous increase in private vehicle ownership, combined with limited urban land availability, has created a severe parking crisis. Most residential and commercial buildings fail to allocate adequate parking space due to high land prices and poor enforcement of building regulations.

In densely populated areas of Dhaka, roadside parking has become a common practice, leading to traffic congestion, reduced road safety, and inefficient utilization of urban space. Conventional horizontal parking systems require large ground areas, which are often economically impractical in Bangladesh’s urban context. As a result, vertical parking solutions present a promising alternative for addressing these challenges.

6.2.2 Space Utilization Comparison

Space efficiency is one of the most critical factors for parking system selection in Bangladesh, where land prices are extremely high.

A typical private passenger car occupies approximately **2.5 m × 5.0 m**. When maneuvering space, access roads, and turning clearance are included, a conventional parking system requires approximately **40–45 m² per vehicle**.

In contrast, the proposed DIY robotic vertical parking system utilizes vertical stacking, significantly reducing horizontal land requirements.

6.2.3 Cost Comparison in Bangladesh Context

In Bangladesh, the cost of parking infrastructure is dominated by land value rather than construction cost. In areas such as Mirpur, Dhanmondi, Uttara, or Mohammadpur, land prices typically range between **BDT 25–80 lakh per Katha**, making horizontal parking economically inefficient.

Commercially available automated parking systems are mostly imported and involve high initial investment and maintenance costs. The approximate cost of such systems in Bangladesh ranges from **BDT 30–60 lakh per car**, which is beyond the affordability of small developers and homeowners.

The proposed DIY robotic vertical parking system emphasizes localized fabrication and the use of readily available components.

6.2.4 Numerical Design Example (Dhaka Plot-Based)

To evaluate real-life applicability, a numerical design example is considered based on a typical residential plot in Dhaka.

Assumed Plot Details:

- Plot size: **5 Katha**
- 1 Katha ≈ **67 m²**
- Total land area = **335 m²**

Parking Requirement:

- Number of cars = **8**
- Required parking system: Compact and space-efficient.

Conventional Parking Calculation

Area required per car = **45 m²**

Total area required for 8 cars:

$A_{conventional}=8\times45=360\ m^2$

Since the available land area is **335 m²**, conventional parking **cannot accommodate 8 vehicles**, even if the entire plot is used only for parking.

Proposed Vertical Parking Calculation

Area required per car (vertical system) ≈ **15 m²**

Total area required:

$A_{vertical}=8\times15=120\ m^2$

Remaining usable land:

$A_{remaining}=335-120=215\ m^2$

This remaining area can be utilized for:

- Building footprint
- Green space
- Access roads
- Utility services

Cost Estimation for Dhaka Plot

Estimated cost per car (DIY system) ≈ **6 lakh BDT**

Total system cost:

$C_{total}=8\times6=48$ lakh

Compared to imported systems:

- Imported APS (minimum):

  $8\times30=240$ lakh

  Cost saving:

$240-48=192$ lakh BDT

6.2.5 Practical Feasibility in Bangladesh

The proposed system is technically feasible for implementation in Bangladesh due to the availability of:

- Local steel fabrication workshops
- Electric motors, gearboxes, and sensors
- Skilled technicians familiar with elevators and lifting systems

Power consumption of the system is relatively low, typically **3–5 kW per operation**, resulting in minimal monthly electricity costs. With proper design, the system can also be integrated with backup power or solar energy to mitigate load-shedding issues.

6.2.6 Safety and Regulatory Considerations

For real-life deployment, the system must comply with the **Bangladesh National Building Code (BNBC)**. Essential safety features include:

- Emergency stop mechanism
- Overload protection
- Mechanical locking system
- Fire safety compliance

While the prototype demonstrates basic safety features, these additional systems can be incorporated during full-scale implementation.

6.2.7 Overall Assessment

Based on space efficiency, cost effectiveness, and local manufacturability, the proposed DIY robotic vertical parking system is highly suitable for Bangladesh. The system provides a practical solution for urban parking challenges, particularly for small to medium-scale residential and commercial developments.

6.2.8 Cost Analysis

The total cost of the DIY robotic parking prototype is significantly lower than that of commercially available automated parking systems. Commercial systems often require heavy structural components, industrial controllers, and professional installation, resulting in high costs. In contrast, the DIY system uses affordable components such as Arduino-based controllers, stepper motors, and locally available materials. This cost advantage makes the system suitable for small-scale applications.

6.2.9 Space Efficiency Comparison

Traditional parking systems require large horizontal space for vehicle maneuvering. The proposed robotic parking system utilizes vertical space, allowing multiple vehicles to be parked within the same ground area.

By stacking vehicles vertically, the system significantly reduces land usage. This is particularly beneficial in urban areas where land availability is limited and expensive.

6.2.10 User Experience and Safety Features

The system offers a user-friendly experience through RFID-based authentication and LCD-based status display. Users are guided through simple steps, reducing confusion and manual effort.

Safety features such as limit switches and sensor-based monitoring ensure safe operation. While the prototype includes basic safety mechanisms, real-life systems can incorporate advanced safety features such as emergency stop buttons and fire detection systems.

6.3 Safety Factor Analysis

Safety factor analysis is essential to evaluate the system's ability to withstand loads beyond normal operating conditions. In this project, safety factors were considered during design to account for uncertainties such as dynamic loads and material limitations.

The belt and pulley mechanism was selected with sufficient margin to handle load variations. Structural components were designed to minimize deflection and vibration.

Although physical stress testing with real vehicle loads was not performed, analytical analysis indicates that the system can be scaled safely by using appropriate materials and motors.

6.4 Results and Observations

The testing results demonstrate that the DIY robotic parking system operates reliably under prototype conditions. The system performed consistently across multiple test cycles with minimal errors.

- ✓ Key observations include:
- ✓ Smooth vertical lifting operation
- ✓ Reliable sensor feedback
- ✓ Stable structural behavior

6.5 Summary

This chapter presented detailed performance testing, real-life comparison, and safety factor analysis of the DIY robotic parking system. The results validate the feasibility of the proposed.

CHAPTER 7: CONCLUSION & RECOMMENDATIONS

7.1 Summary of Findings

The primary objective of this project was to design, fabricate, and test a low-cost DIY robotic vertical parking system capable of demonstrating efficient space utilization through automation. The project focused on addressing the limitations of conventional horizontal parking systems, particularly high land usage and cost inefficiency.

The experimental results and performance testing confirmed that the developed prototype successfully achieved its intended objectives. The system demonstrated reliable vertical lifting, accurate slot detection using sensors, and smooth parking and retrieval operations. The Arduino-based control system efficiently coordinated sensor inputs and actuator outputs, ensuring safe and sequential operation.

Although the prototype was constructed as a scaled-down model using toy vehicles, the design methodology and analytical calculations were carried out considering real-life vehicle loads. This approach confirms that the proposed system concept is technically feasible for real-world application when implemented using industrial-grade components.

Overall, the findings indicate that the DIY robotic parking prototype meets the functional, mechanical, and automation objectives set at the beginning of the project.

7.2 Conclusion

This project successfully demonstrates the feasibility of a DIY robotic vertical parking system as an alternative to expensive commercial parking solutions. The integration of mechanical design, electronic control, and automation techniques resulted in a compact and efficient parking system that maximizes vertical space utilization.

The study highlights that even with limited resources and low-cost components, it is possible to develop an automated parking solution suitable for small-scale applications such as residential buildings and small commercial facilities. The use of a belt-and-pulley lifting mechanism, microcontroller-based control, and sensor-driven automation proved to be effective for prototype-level implementation.

From an engineering perspective, the project provided practical exposure to system design, fabrication, testing, and problem-solving. The results indicate that with appropriate scaling, safety enhancements, and structural reinforcement, the proposed system can be implemented in real-life scenarios.

7.3 Advantages of the Proposed DIY Robotic Parking System

7.3.1 Efficient Space Utilization

The most significant advantage of the proposed system is its ability to utilize vertical space effectively. By stacking vehicles vertically, the system reduces the ground area required for parking compared to traditional horizontal parking systems.

7.3.2 Low Cost and Affordability

The DIY approach significantly reduces system cost by using readily available components such as Arduino controllers, stepper motors, and basic mechanical structures. This makes the system accessible to homeowners and small businesses.

7.3.3 Automation and User Convenience

Automated operation eliminates the need for manual parking and reduces human error. Features such as RFID-based access control and LCD-based system feedback enhance user convenience and ease of operation.

7.3.4 Scalability and Modularity

The modular design allows the system to be expanded by adding additional parking levels or slots without major redesign. This scalability increases its applicability across various parking requirements.

7.4 Limitations of the System

7.4.1 Prototype Load Capacity

The developed prototype is not capable of handling real vehicle loads. Although analytical calculations were performed for real-life conditions, physical testing was limited to toy vehicles.

7.4.2 Power Dependency

The system relies entirely on electrical power for operation. In the absence of power backup, system operation may be interrupted.

7.4.3 Limited Safety Features

The prototype includes basic safety mechanisms such as limit switches and sensors. Advanced safety features required for commercial deployment, such as fire detection and emergency braking, were not implemented.

7.4.4 Maintenance Requirements

Mechanical components such as belts and pulleys require periodic inspection and maintenance to ensure smooth operation and prevent wear-related failures.

7.5 Recommendations and Future Scope

7.5.1 Solar Power Integration

Future versions of the system can integrate solar panels to reduce dependence on grid power. Solar energy can improve sustainability and reduce operating costs.

7.5.2 IoT-Based Monitoring and Control

The system can be enhanced by integrating Internet of Things (IoT) technology. A mobile application can allow users to monitor parking availability, control parking operations, and receive real-time notifications.

7.5.3 Advanced Safety Systems

Additional safety features such as emergency stop buttons, overload detection, fire sensors, and collision avoidance systems can be incorporated to improve safety and reliability.

7.5.4 Structural and Load Optimization

For real-life implementation, the structure can be optimized using high-strength materials and advanced lifting mechanisms such as hydraulic systems to handle heavier loads.

7.5.5 AI-Based Slot Management

Artificial intelligence algorithms can be applied to optimize slot allocation and minimize retrieval time, further improving system efficiency.

7.6 Final Remarks

In conclusion, the DIY robotic vertical parking system developed in this project demonstrates a practical and economical approach to solving urban parking challenges. The project fulfills the academic requirements of a final-year Mechanical Engineering project and provides a strong foundation for future research and development in automated parking systems.

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