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Smart Parking System: A Comprehensive Research

[1]Tejas Kotekar, [2]Ziyad Khan

[1]Student, [2]Student

[1]Department of Computer Engineering,

[1]Terna Engineering College, Navi Mumbai, India

Abstract: The Smart Parking System using Arduino Uno is a compact and efficient solution designed to address the growing parking challenges in urban areas. This system utilizes the Arduino Uno microcontroller as its core component, integrated with IR sensors, a servo motor, and an LCD display to automate parking slot detection and gate operations. The system operates by detecting vehicle presence at the entry and exit points using IR sensors, updating slot availability in real time on an LCD display, and controlling the entry and exit gates through a servo motor. This setup ensures seamless vehicle flow and reduces manual intervention, making it ideal for small and medium-sized parking lots. The proposed system overcomes limitations such as difficulty in finding available parking, traffic congestion, lack of automation and inefficient use of space through automated slot detection, cost-effective design, simplified setup and seamless integration with automated gate control via a servo motor and real-time display of slot status on an LCD, the system provides an efficient and user-friendly experience.

Index Terms - Arduino Uno, I2C, Servo Motor, IR Sensor

I. INTRODUCTION

In recent years, the explosive growth in urban populations and vehicle ownership has placed tremendous pressure on existing infrastructure, especially in metropolitan areas. One of the most significant challenges that modern cities face today is the unavailability of efficient and organized parking systems. The growing number of vehicles leads to congestion, increased pollution, time wastage, and unnecessary fuel consumption, all of which demand a technological solution. The development of a Smart Parking System utilizing the Internet of Things (IoT), microcontrollers, sensors, and automation is a promising step toward resolving this urban issue.

A Smart Parking System is an automated infrastructure that leverages real-time data acquisition and processing to facilitate vehicle parking with minimal human intervention. This system enables users to locate vacant parking spaces, reserve them, and even handle payments via a mobile or web interface. By integrating microcontrollers and sensors, such as ultrasonic sensors, the system can monitor slot occupancy and direct vehicles accordingly, thereby eliminating the traditional trial-and-error method of finding parking spaces.

Jaafar Ahmed Abdulsaheb et al. (2024) emphasize the potential of IoT in parking management, highlighting how cloud connectivity, wireless networks, and embedded systems collectively contribute to a smart infrastructure that is both user-centric and efficient [1]. In their work, they present a fully IoT-based system architecture that automatically detects vehicle entry and updates slot availability in real time. Similarly, Sakshi Kharade et al. (2024) focus on the integration of sensor-based automation with mobile applications to enhance user experience and convenience in accessing parking slots [2]. Their model also shows how Arduino microcontrollers, combined with IoT platforms, can be deployed for real-world smart parking implementations.

The core functionality of most smart parking systems lies in the detection mechanism used to sense whether a parking slot is occupied or not. Ultrasonic sensors, due to their accuracy and low cost, are commonly employed for this purpose. As described by Badri Narayan Mohapatra et al. (2020), ultrasonic sensors interfaced with microcontrollers like Arduino Mega can reliably detect obstacles (i.e., parked vehicles) within a specified range and relay that data to a central processing unit [3]. Their system also explores the scalability of parking systems for multi-slot configurations.

Boopathi Kumar E et al. (2024) take this idea further by implementing an Arduino-based prototype using multiple sensors and a basic graphical user interface for monitoring [4]. Their research underlines the importance of real-time feedback and visual indicators (e.g., LEDs or display boards) to guide the driver to an available space. Mr. Basavaraju (2015) was one of the early adopters of integrating IoT into parking systems. His work presents an automatic system where RFID tags and Wi-Fi modules transmit data to cloud servers, showcasing how even basic IoT principles can enhance traditional parking infrastructure [5].

The benefits of such smart systems are multi-fold. S.K. Satyanarayana et al. (2022) emphasize that Arduino-based parking systems are not only cost-effective but also significantly reduce human effort, especially in areas like malls, offices, and institutions [6]. By using infrared or ultrasonic sensors and incorporating logic-based decision-making within the code, vehicles can be automatically guided to their slots, reducing traffic inside parking zones.

An emerging trend in recent research is the development of automatic self-parking systems**.** These systems not only manage parking availability but also support automatic vehicle maneuvering into the designated slots. Katkar Kalyani et al. (2021) propose an advanced design that uses multiple Arduino modules and motor drivers to simulate self-parking functionality [7]. This level of automation brings the system closer to the goals of autonomous smart cities.

Moreover, RFID-based systems are becoming more common in controlled-access environments. In their 2018 paper, S. Prince Samuel et al. design a smart parking prototype using RFID readers that allow entry only to authorized vehicles while simultaneously updating slot availability on the server [9]. This is particularly effective for gated communities, corporate parks, and university campuses. Sabiya Sultana et al. (2017) also demonstrate an Arduino Uno-based parking model using basic IR sensors, indicating that such systems are feasible for small-scale implementations like school and college campuses [8].

Our paper, Smart Parking System, integrates these key concepts and technologies to build an efficient, scalable, and user-friendly parking management solution. By using an Arduino microcontroller, ultrasonic sensors, and a simple web interface, we aim to create a system that detects slot availability and guides the user to the correct location. The system also plans to include basic access control features and logging mechanisms to track entry and exit times for analytical purposes.

II. Related Work

Over the past decade, numerous attempts have been made to automate parking systems using embedded systems, sensors, and wireless communication technologies. The purpose of these systems is to eliminate manual efforts, reduce traffic congestion, and enhance user convenience by offering real-time parking slot updates. Despite significant progress, most existing systems suffer from limitations in scalability, integration, and affordability.

One of the earliest IoT-based parking frameworks was presented by Mr. Basavaraju (2015), who developed a basic system integrating RFID and Wi-Fi modules to transmit slot occupancy data to the cloud. Although it provided remote access to parking information, it lacked real-time responsiveness and detailed authentication logic for secure access [5].

Building upon these early ideas, RFID-based systems became popular for secure entry and exit management. S. Prince Samuel et al. (2018) proposed an RFID-enabled smart parking system that allowed entry to vehicles only with registered RFID tags, thereby enhancing access control. However, it was not integrated with modern smartphone interfaces or cloud-based analytics, limiting user interaction and scalability [9].

Several systems have focused on sensor-based automation using microcontrollers. For example, the work by Sabiya Sultana and Sadaf Anjum (2017) used IR sensors and an Arduino Uno board to track parking slot occupancy. While effective for small-scale use cases, it offered minimal user feedback and no remote access [8]. Similarly, Boopathi Kumar E et al. (2024) designed a sensor-driven Arduino system that employed IR sensors and an LCD display for real-time slot updates. Though simple and affordable, this model lacked scalability and user authentication features [4].

Another practical and low-cost approach was presented by S.K. Satyanarayana et al. (2022), where an Arduino-based parking assistance system utilized basic IR detection for monitoring vehicle entry. This solution targeted educational and residential complexes but did not provide an online interface or access control mechanism [6].

Recent research has attempted to incorporate both automation and intelligence into parking systems. For instance, Jaafar Ahmed Abdulsaheb et al. (2024) presented a robust IoT-based smart parking model where parking slot data was collected via sensors and processed using cloud platforms to allow real-time data access and management. This approach successfully addressed the problem of data centralization and remote monitoring, yet still depended heavily on stable internet connectivity [1].

A more modern and efficient design was proposed by Sakshi Kharade et al. (2024), who combined IoT modules with Arduino and a mobile interface for real-time interaction with users. This system allowed users to check availability before reaching the parking location and incorporated basic automation for gate control. Nevertheless, the lack of sophisticated analytics or security protocols remained a concern [2].

The use of ultrasonic sensors was emphasized by Badri Narayan Mohapatra et al. (2020), whose system could detect parking occupancy using non-contact methods. Their microcontroller-based solution demonstrated reliability in occupancy detection but did not include any access control or data visualization features [3].

Moreover, advanced designs now explore autonomous self-parking simulations. Katkar Kalyani. (2021) implemented a prototype using Arduino, motors, and sensors to maneuver a vehicle into a parking space automatically. While promising, this research is largely limited to controlled environments and lacks deployment readiness for real-world traffic scenarios [7].

From the above studies, it is evident that while numerous systems exist targeting automation, detection, and security, most lack a combination of scalability, real-time feedback, user authentication, and ease of integration. The proposed Smart Parking System in this project aims to bridge these gaps by using an Arduino Uno, IR sensors, a servo-controlled gate, and RFID authentication. The system ensures that only authorized vehicles gain access, monitors slot availability in real-time, and displays live status via an LCD screen, thereby making it suitable for both small and medium-scale parking infrastructures.

III. Methodology

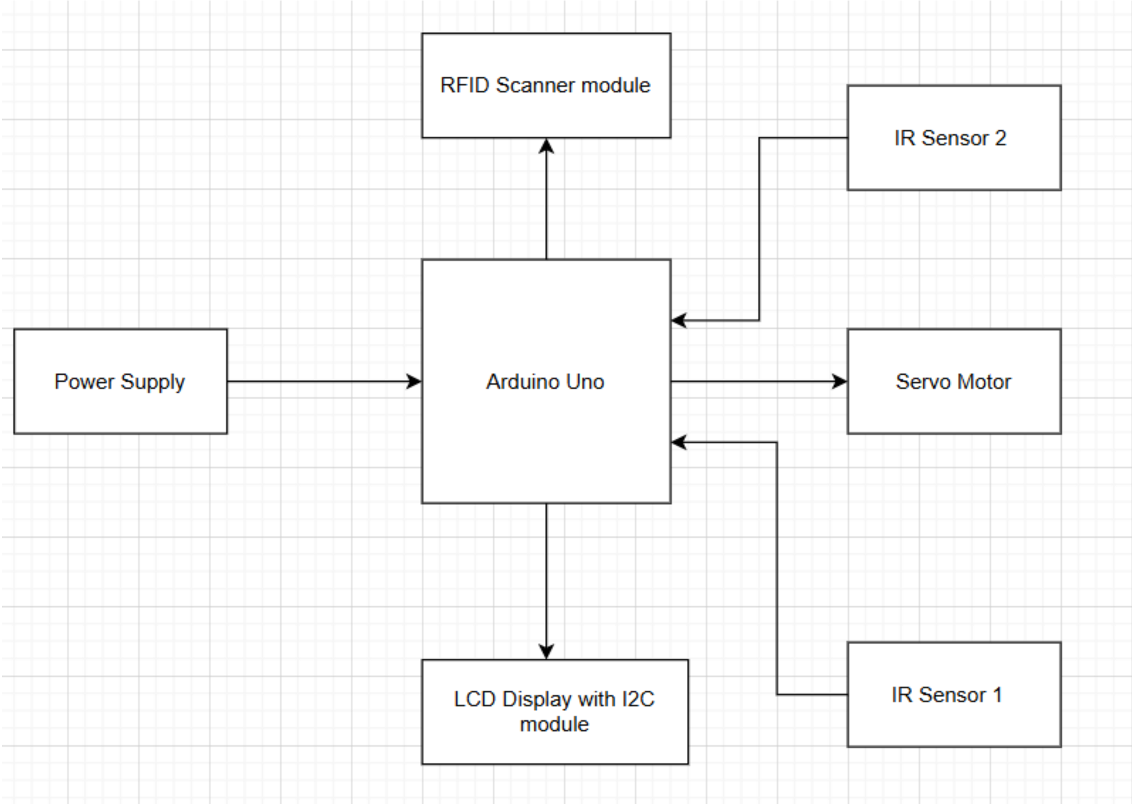


Figure 1: Block Diagram

This section illustrates a centralized approach with the Arduino Uno serving as the main controller connecting to all peripheral components. This represents a single-controller embedded system methodology where:

1. **Sensing Module**: Two IR sensors positioned strategically to detect vehicle entry and exit.
2. **Authentication Module**: RFID scanner for validating access credentials.
3. **Output Module**: Servo motor for gate operation and LCD display for user feedback.
4. **Power Management**: Dedicated power supply for the entire system.

A. Proposed System

The proposed system aims to develop an affordable, scalable, and secure RFID-based Smart Parking System using Arduino Uno and IR sensors. This system will automate the entry and exit process through RFID tag verification and control gate movement using a servo motor. Real-time parking slot availability will be monitored via IR sensors and displayed on a 16x2 LCD screen with an I2C module for efficient user feedback. Unlike previous models, this design focuses on enhancing user authentication, improving slot visibility, and reducing manual intervention. The system is tailored for small to medium-scale parking areas such as colleges, offices, and residential complexes, with the potential for future integration with cloud platforms or mobile applications for remote access and monitoring. By leveraging low-cost components and combining RFID access with slot detection, the proposed system ensures a practical and intelligent approach to modern parking management.

A.1 System Design

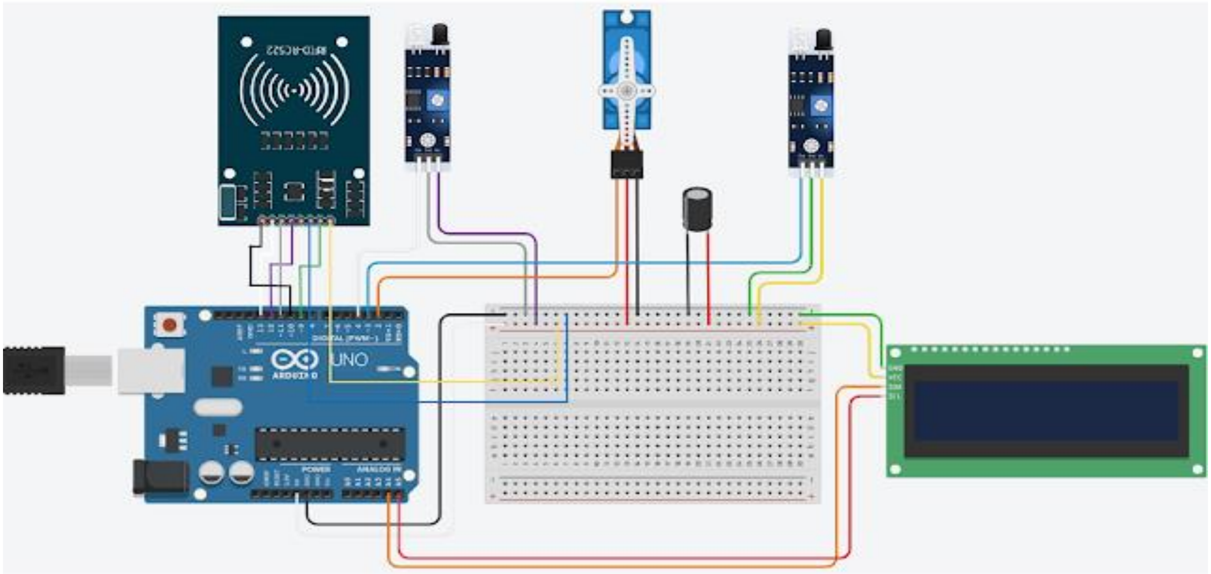


Figure 2: System Design

1. **Microcontroller: Arduino Uno**

- Acts as the brain of the system.
- Controls inputs from the sensors and RFID reader.
- Outputs data to the LCD and servo motor.

2. **RFID Module (RC522)**

- **Purpose**: Detects authorized RFID tags to allow vehicle entry.
- **Connections**:
  - Connected to the Arduino via SPI (MOSI, MISO, SCK, SDA, RST).
  - Used for user authentication to control gate access.

3. **IR Sensors (2 Units)**

- **Purpose**:
  1. **Entry Sensor** – Detects vehicle arrival at the gate.
  2. **Exit Sensor** – Detects when the vehicle leaves.
- **Connections**:
  - Connected to digital pins of Arduino for sensing HIGH/LOW signals.

4. **Servo Motor**

- **Purpose**: Controls the gate barrier based on RFID verification.
- **Connections**:
  - Connected to a PWM-enabled digital pin.
  - Rotates to allow or block vehicle entry.

5. **16x2 LCD Display (with I2C Module)**

- **Purpose**: Displays system messages such as:
  - “Access Granted/Denied”
  - “Slot Available/Full”
- **Connections**:
  - Connected via I2C interface (SDA, SCL).
  - Reduces wiring complexity.

A.2 System Architecture:

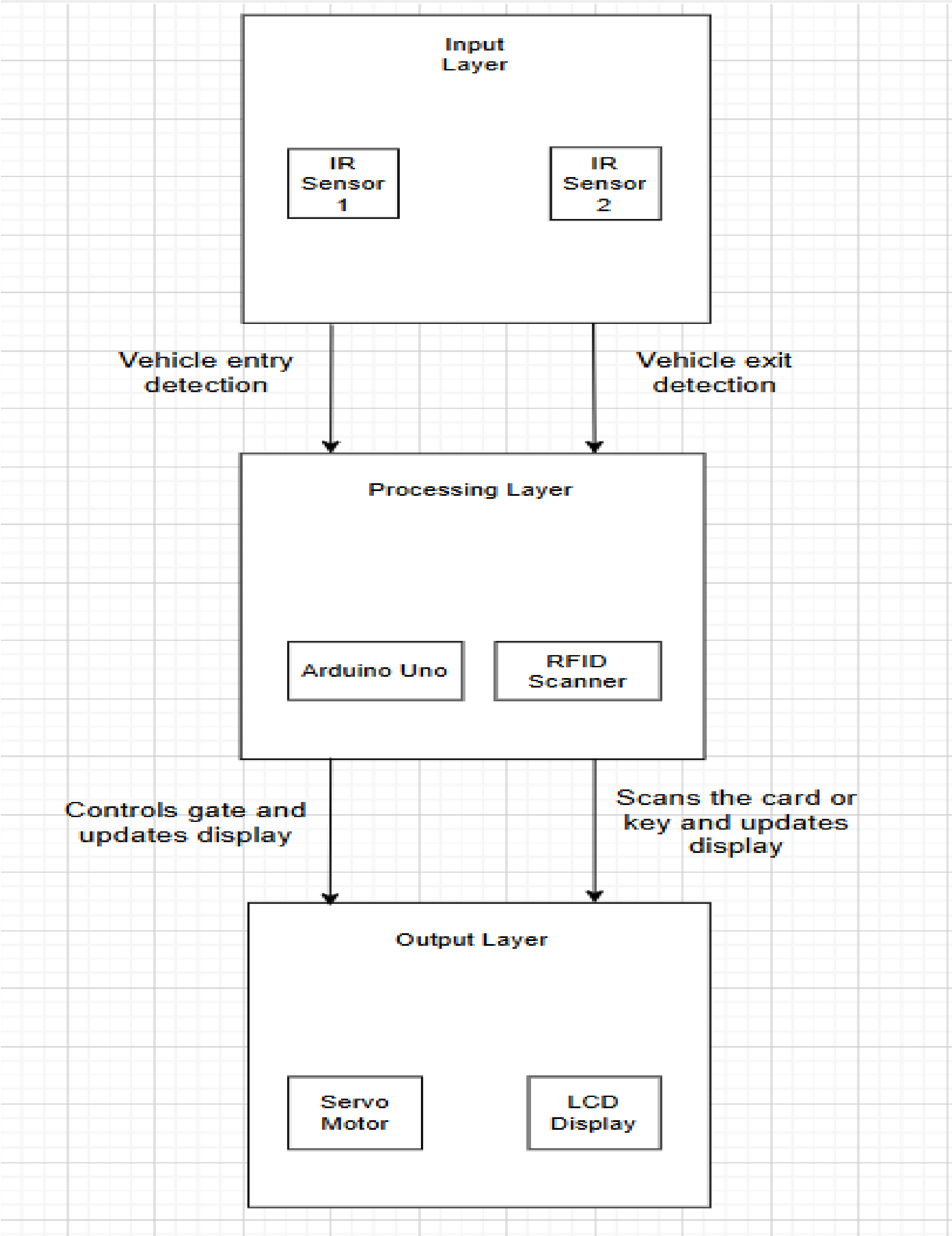


Figure 3: System Architecture

The architecture (Figure 3) represents a complete embedded system for automating parking access control, combining sensors for detection, RFID for authentication and sensors for physical control, all managed by an Arduino Uno microcontroller.

1. **Input Layer:**

- Contains two IR Sensors (IR Sensor 1 and IR Sensor 2).
- These sensors handle vehicle entry and exit detection.
- They monitor when the cars enter and leave the parking area.

2. **Processing Layer:**

- Features an Arduino Uno for system control.
- Includes an RFID Scanner for identification.
- The Arduino controls the gate and updates the display.
- The RFID Scanner reads the card/keychain ID and provides information to update the display.

3. Output Layer:

- Contains a Servo Motor for gate operation.
- Includes an LCD Display to show system information.
- The servo motor operates the physical barrier/gate.
- The LCD displays information like parking availability and RFID authentication status.

IV. IMPLEMENTATION

The development and implementation of the Smart Parking System followed a step-by-step approach. We first tested each component separately before connecting them to the Arduino Uno. The software was built gradually, starting with basic functions and adding features one by one. We faced some challenges, such as IR sensors sometimes giving false readings and the RFID scanner having trouble reading tags at certain angles. To solve these issues, we improved the sensor positioning and added filtering in the code. We also had to fix power problems that caused the system to reset when the servo motor operated. After several rounds of testing and improvements, we achieved a reliable system that accurately detects vehicles and processes RFID tags quickly, with the gate opening and closing smoothly in response.

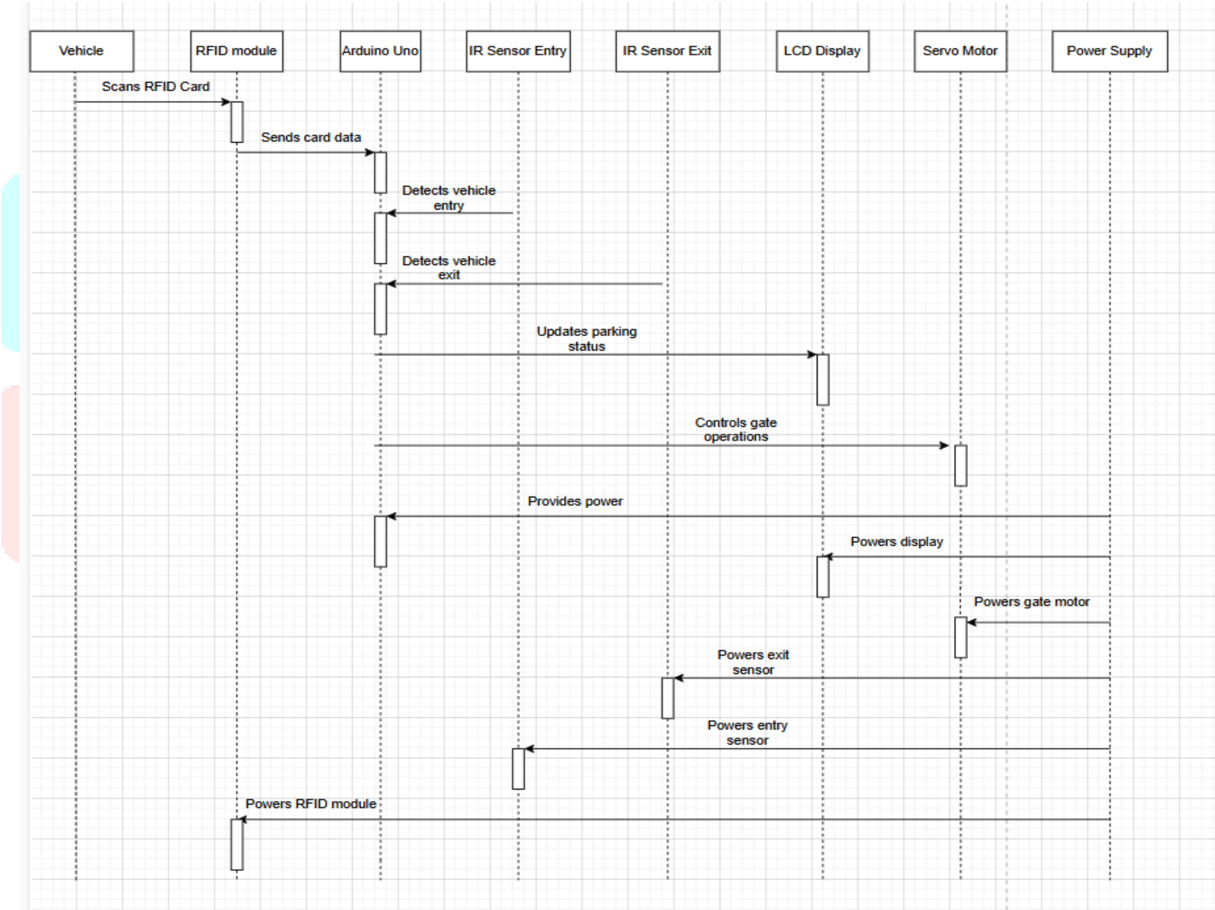


Figure 4: Sequence Diagram

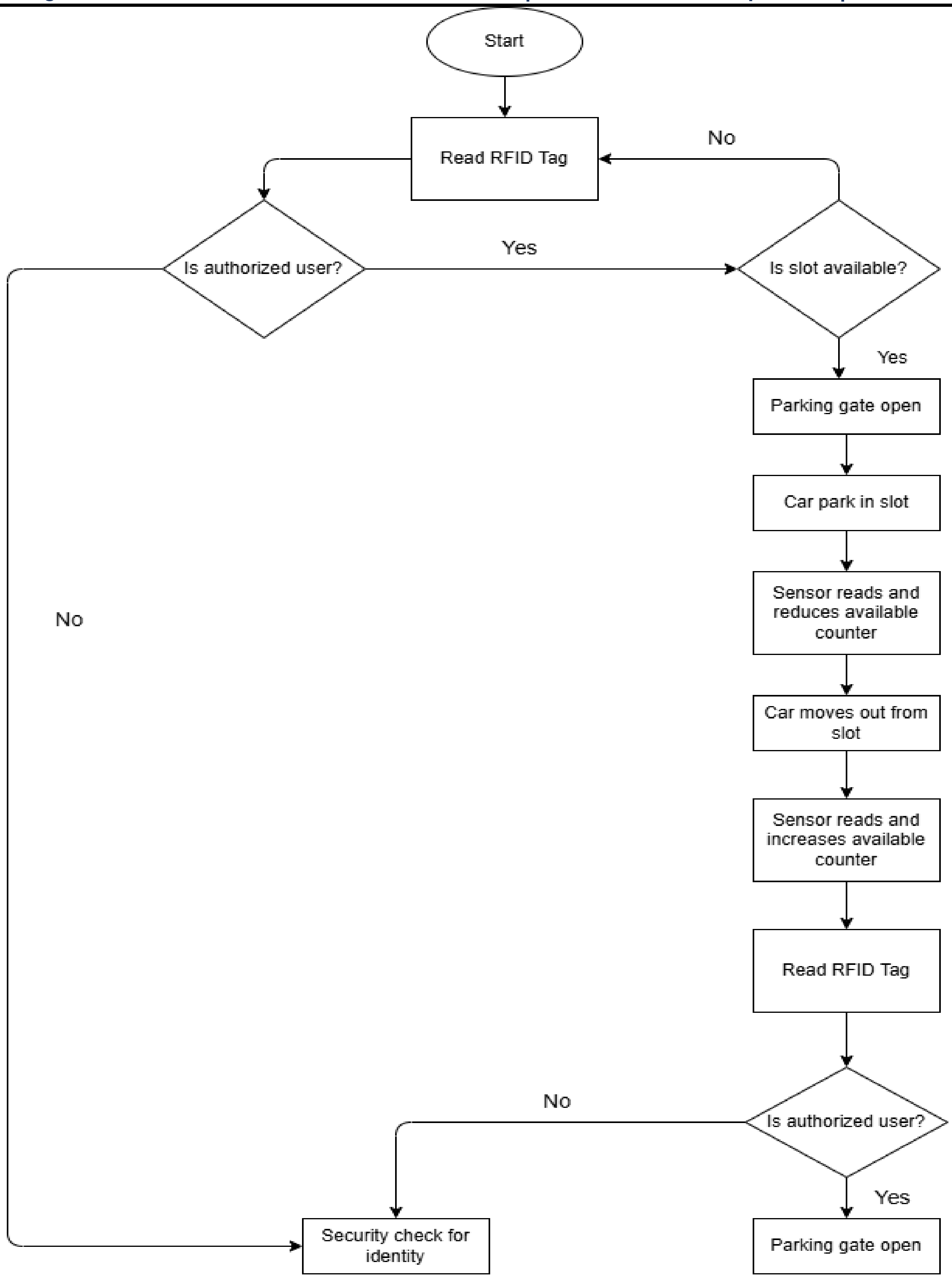
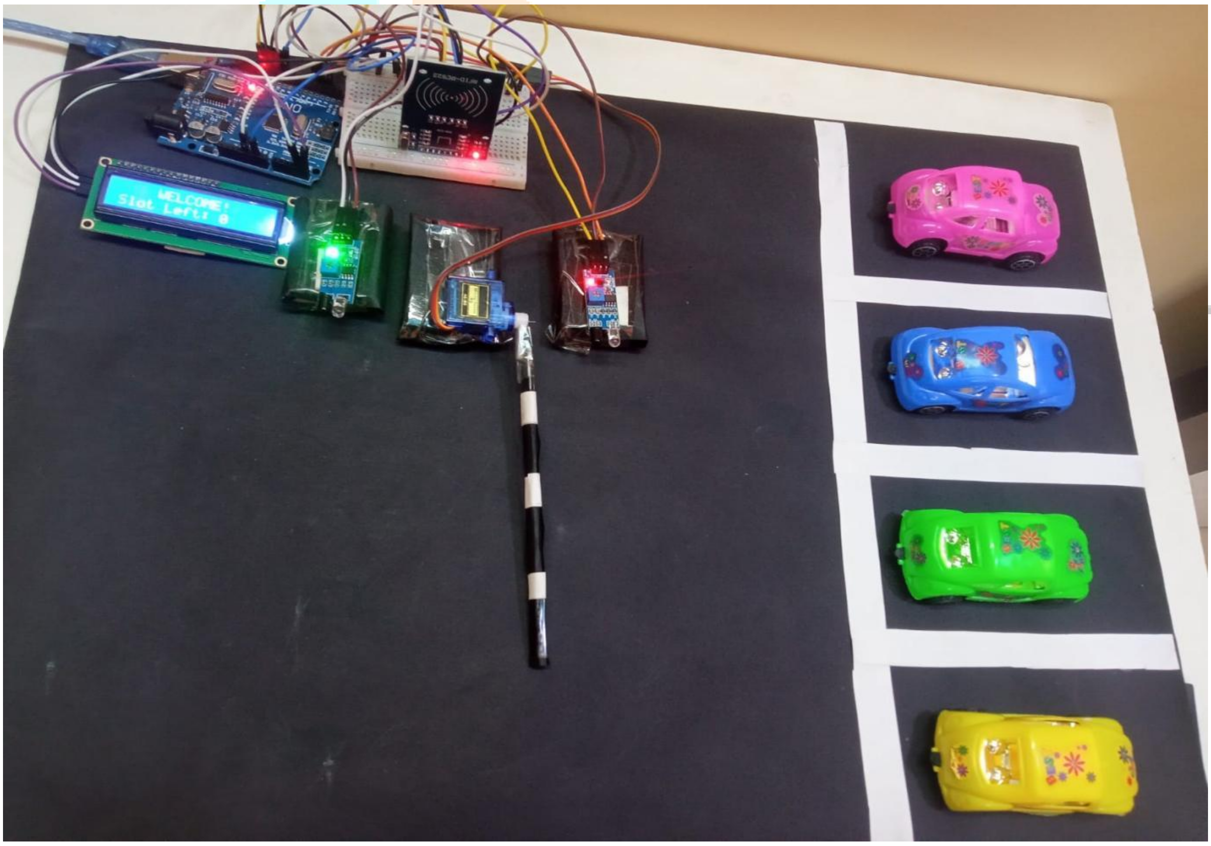


Figure 5: Flowchart

Working:

- The system is powered by a dedicated power supply connected to the Arduino Uno.
- IR Sensor 1 detects vehicles approaching the entry point.
- The RFID Scanner module reads the vehicle's RFID keychain ID or card ID.
- The Arduino processes this data to authenticate access.
- If authorized, the Arduino signals the Servo Motor to open the gate.
- The LCD Display shows relevant information (access granted, parking availability).
- IR Sensor 2 detects when the vehicle has completely entered.
- Once the vehicle is clear, the Arduino signals the Servo Motor to close the gate.
- The same process works in reverse for exiting vehicles.

V. RESULTS AND DISCUSSION



The Smart Parking System was successfully designed and implemented using Arduino Uno and various hardware components such as IR sensors, an RFID module, a servo motor and a 16x2 LCD display with I2C module. The system was tested under various conditions to validate its performance.

A.1 Result:

1. Vehicle Detection:

- IR sensors accurately detected vehicle entry and exit.
- The system successfully tracked vehicle direction and movement (entry vs. exit).

2.RFID Authentication:

- The RFID reader correctly identified valid and invalid RFID tags.
- Only authorized tags were allowed entry, ensuring secure access.

3.Servo Motor Gate Control:

- Servo motor opened and closed the gate smoothly in synchronization with vehicle detection and authentication status.

4.LCD Display Feedback:

The LCD provided real-time updates such as:

- Welcome messages
- Card scanning instructions
- Slot availability
- Gate status (opened/closed)
- Error messages (e.g., "Wrong card", "Parking Full")

5.Slot Management Logic:

- The system dynamically updated the available parking slots.
- Correctly prevented access when all slots were full.
- Increased slot count on vehicle exit, ensuring real-time slot tracking.

6.System Stability and Reliability:

- The system operated continuously during testing without performance degradation.
- Components responded accurately without lag or misreading.

7.Component Integration:

- All hardware components (RFID, IR sensors, servo motor, LCD) were integrated successfully and worked as a cohesive system.

A.2 Comparison with Existing Solution:

Compared to the existing solution (Traditional Parking System), the proposed Smart Parking System offers greater automation, security, and efficiency. Traditional systems often rely on manual supervision for vehicle detection and access control, resulting in slower processing and higher operational costs. In contrast, the smart system uses IR sensors for real-time vehicle detection, RFID tags for secure access, and an LCD to display parking slot availability, reducing human involvement and enhancing user convenience. Additionally, automated gate control using a servo motor improves traffic flow, and the system is cost-effective and easily scalable for future expansions.

Aspect	Traditional Parking System	Smart Parking System
Vehicle Detection	Manual based	Automated using sensors
Access Control	Guard operated	Secure RFID-based access with authorized tags
Slot Availability Monitoring	Not updated in real time/Requires manual checking	Real time slot tracking and display on LCD
User Feedback System	None or verbal/manual instructions	LCD screen displaying messages and live slot updates
Security Level	Low (easily bypassed or manipulated)	High (authorized entry only through RFID validation)
Scalability	Limited	Easy to scale with additional sensors and controller units

Cost Effectiveness	High operational costs due to manpower	Low-cost hardware and minimal maintenance
Response Time	Slower due to manual processing	Fast, automated response through code and sensors
Error Rate	More (Human mistakes or errors)	Low

Table: Comparison between Traditional and Smart Parking System

VI. Conclusion:

The exponential growth in vehicle ownership and urban population has led to several challenges in managing limited parking infrastructure. Inefficient parking systems contribute to traffic congestion, fuel wastage, user frustration, and increased carbon emissions. The Smart Parking System designed and developed in this project aims to address these problems through automation, security, and real-time monitoring.

This project utilizes a combination of Arduino Uno**,** IR sensors**,** servo motors**,** RFID authentication and an LCD interface to create an affordable and intelligent parking solution. The use of IR sensors allows for accurate and continuous monitoring of slot occupancy, while servo motors automate the entry and exit gates, ensuring a smooth vehicle flow. RFID authentication enhances security by ensuring that only authorized users are permitted access to the parking area. Meanwhile, the LCD display acts as a user-friendly interface, providing live updates on parking availability.

The system was implemented with cost-effectiveness in mind by using open-source hardware and affordable sensors, making it suitable for small to medium-sized facilities such as residential complexes, educational institutions, shopping malls, and office campuses. Its modular architecture allows for easy expansion, supporting scalability and adaptation for larger setups. Real-time data accuracy and system responsiveness were key priorities during development, and the project successfully achieved its objective of offering a seamless and secure parking experience with minimal human intervention.

Additionally, the design emphasizes sustainability by minimizing vehicle idling time and emissions, aligning with broader goals of smart urban infrastructure and green mobility. Through this project, we demonstrated that even low-cost embedded systems could be effectively employed to solve large-scale, real-world problems when designed strategically.

VII. ACKNOWLEDGEMENT:

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