

IoT-Enabled Smart Parking Framework with Electric Vehicle Charging Demonstration

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Abstract: As cities deal with more cars, finding a parking spot has turned from a small annoyance into a major cause of traffic jams and pollution. Past research has used sensors, such as infrared and ultrasonic tools, to determine whether a car is parked in a spot or to monitor the entrances and exits. However, many of these older projects only perform one function at a time, such as checking for empty spots, while ignoring automatic gates or the need for electric vehicle (EV) charging stations.

This project is different because it integrates all these features into a single system, which is run by an ESP32 microcontroller. Unlike basic models, this system divides parking spots into two groups: one for fuel cars and another for electric vehicles. It shows exactly how many spots are left for each type on a simple screen. Most importantly, the system does more than just watch the spots; it uses an automatic gate that opens and closes on its own and even shows a basic method for charging electric cars. By combining smart parking with a charging test, this project offers a cheap and useful way to build better parking systems for future cities.

Keywords: Smart Parking System, ESP32 Microcontroller, EV Charging Demonstration, Infrared sensors, Ultrasonic sensors, Automated Gate Control.

1. INTRODUCTION

In recent years, the Internet of Things (IoT) has significantly transformed modern lifestyles by connecting physical devices to the Internet so that they can share data and work together. One of the major applications of this technology is in smart city infrastructure, where sensors and microcontrollers are used to make city life easier and more efficient than before. As more people move to cities and buy cars, parking management has become a significant challenge.

In many busy areas, drivers spend considerable time and fuel searching for vacant parking spaces looking for a place to park. This search leads to heavy traffic jams and increased air pollution. Most traditional parking lots are manual, which means that they do not have a way to inform you if a spot is empty until you are already inside. Therefore, smart parking systems are necessary. By using sensors to monitor every spot, a system can tell drivers exactly where to go, thereby saving time and reducing stress.

Simultaneously, the world is shifting away from petrol and diesel cars toward Electric Vehicles (EVs) to help the environment. However, despite the growing popularity of EVs, many users hesitate to adopt them due to concern about charging locations, commonly known as range anxiety. Because charging an EV takes much longer than filling a gas tank, it makes sense to charge the car while it is parked.

Therefore, modern parking lots need to do more than just provide space; they need to become "smart" hubs that can also charge vehicles. This project introduces a single system that uses an ESP32 microcontroller to handle all tasks simultaneously. The proposed system automates gate operation and monitors parking slot occupancy for both gas and electric cars and shows how a charging station can be built into the parking slot. This combined approach is key to building a cleaner and more organized transportation system for the future.

In this study, a prototype smart parking management system was designed and implemented using an ESP32 microcontroller. The proposed system includes automated vehicle entry and exits control using ultrasonic sensors and a servo-operated gate. Parking slots are monitored using infrared sensors, and LED indicators are used to show the availability of slots. A 16x2 LCD display provides real-time information about the number of available fuel and EV parking slots. This project demonstrates how charging functionality can be integrated into future smart parking infrastructures.

2. LITERATURE REVIEW

Several researchers have investigated smart parking systems and EV charging integration to improve urban transportation efficiency and reduce traffic congestion.

Lekshmi et al. [1] developed an IoT-based parking system using Raspberry Pi with wireless EV charging support.

Sabir et al. [2] designed an Arduino-based parking system using infrared (IR) sensors for slot detection and a servo motor for automated gate control.

Bokhari [3] introduced solar energy-powered eco-parking platforms for EV charging applications.

However, many existing systems focus on parking management or EV charging separately. The proposed system combines automated gate control, slot monitoring, and EV charging demonstration using the ESP32 platform.

3. METHODOLOGY

The proposed smart parking system was designed around the ESP32 microcontroller, which acts as the main controller responsible for coordinating all system operations. The ESP32 processes the signals from different sensors and controls the actuators and display modules used in the parking system. The overall architecture includes vehicle detection sensors, a gate control mechanism, parking slot indicators, and a display unit for real-time information.

At the parking entrance, two ultrasonic sensors were installed to detect vehicle movement near the gate area. The first ultrasonic sensor was placed outside the gate to detect vehicles approaching the parking entrance. The second ultrasonic sensor was positioned near the gate to detect vehicles passing through it. Based on the signals received from these sensors, the ESP32 controls a servo motor that opens the gate when a vehicle arrives and closes it after the vehicle has entered the parking area.

Within the parking area, six parking slots were available for vehicles. Each slot is equipped with an infrared (IR) sensor that detects the presence of a vehicle in the slot. When a vehicle occupies a particular slot, the corresponding IR sensor sends a signal to the ESP32, which activates an LED indicator assigned to that slot. This LED indicates that the slot is currently occupied.

For demonstration purposes, parking slots were categorized into two types: slots reserved for fuel-powered vehicles and slots reserved for electric vehicles (EVs). This classification allows the system to monitor the availability of both types of parking spaces separately.

A 16×2 LCD display was connected to the ESP32 to show real-time information about parking availability. The display continuously updates the number of free EV slots and fuel vehicle slots so that users can easily see the current parking status.

In addition to parking management, a simple EV charging demonstration was included in the system. For EV-designated slots, a GPIO pin of the ESP32 was used to provide a controlled power output through a connector wire. When a toy electric vehicle is connected to this connector, an LED inside the vehicle is turned on to represent the charging process. This feature demonstrates how EV charging capabilities can be integrated with smart parking infrastructure in future implementations.

The overall system architecture of the proposed smart parking system is shown in Fig. 1.

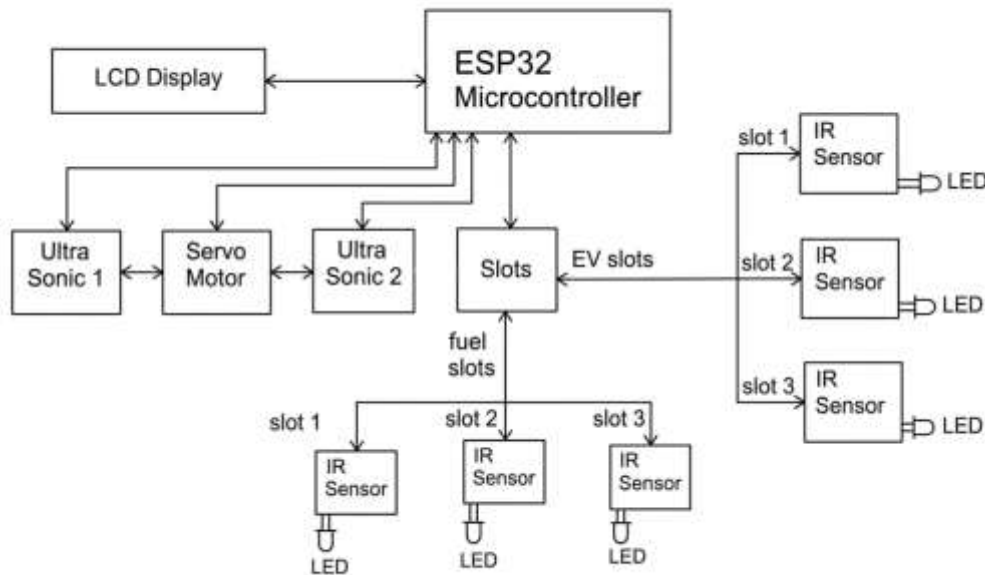


Fig 1: Block Diagram of Smart Parking System

3.1 HARDWARE COMPONENTS

The proposed smart parking prototype was developed using several electronic components that work together to detect vehicles, control the gate mechanism, and display parking information. Each part has a specific job to do in the system.

3.1.1 ESP32 Microcontroller

The main part of the entire system was the ESP32 microcontroller. It receives signals from the sensors installed in the parking area and processes the information to control the gate, LED indicators, and display module. The ESP32 was selected because it provides multiple GPIO pins, good processing capability, and built-in communication features, which make it suitable for embedded system applications.

3.1.2 Ultrasonic Sensors (HC-SR04)

Two HC-SR04 ultrasonic sensors were used near the parking gate for vehicle detection. The first sensor was placed outside the gate to detect vehicles approaching the parking entrance. The second sensor was placed slightly inside the gate area to detect vehicles passing through the gate. Based on the measured distance values, the system determines when to open or close the gate.

3.1.3 Infrared Sensors

Six infrared (IR) sensors were installed in the parking slots. Each IR sensor is responsible for detecting the presence or absence of a vehicle in a particular parking slot. When a vehicle occupies a slot, the sensor sends a signal to the ESP32 indicating that the slot is no longer available.

3.1.4 Servo Motor

A servo motor was used to control the opening and closing of the parking gate. The ESP32 sent control signals to the servo motor, which rotates to a predefined angle to open the gate when a vehicle arrives and returned to its original position after the vehicle entered.

3.1.5 LCD Display (16×2)

A 16×2 LCD display was connected to the ESP32 to provide real-time parking information. The display shows the number of available parking spaces for both fuel vehicles and electric vehicles. This helps users easily understand the current parking status.

3.1.6 LED Indicators

LED indicators were used for the visual representation of slot occupancy. Each parking slot has a corresponding LED that turns on when the slot is occupied and remains off when the slot is free. This facilitates the rapid identification of available parking spaces.

3.1.7 Toy EV Vehicle with LED

A toy electric vehicle with a small LED was used to demonstrate the EV charging functionality. When the toy EV is connected to the charging connector powered by the ESP32 GPIO output, the LED lights up, representing the charging process. This serves as a basic demonstration of how EV charging infrastructure could be integrated into smart parking systems.

The detailed circuit connections of the system are illustrated in Fig. 2.

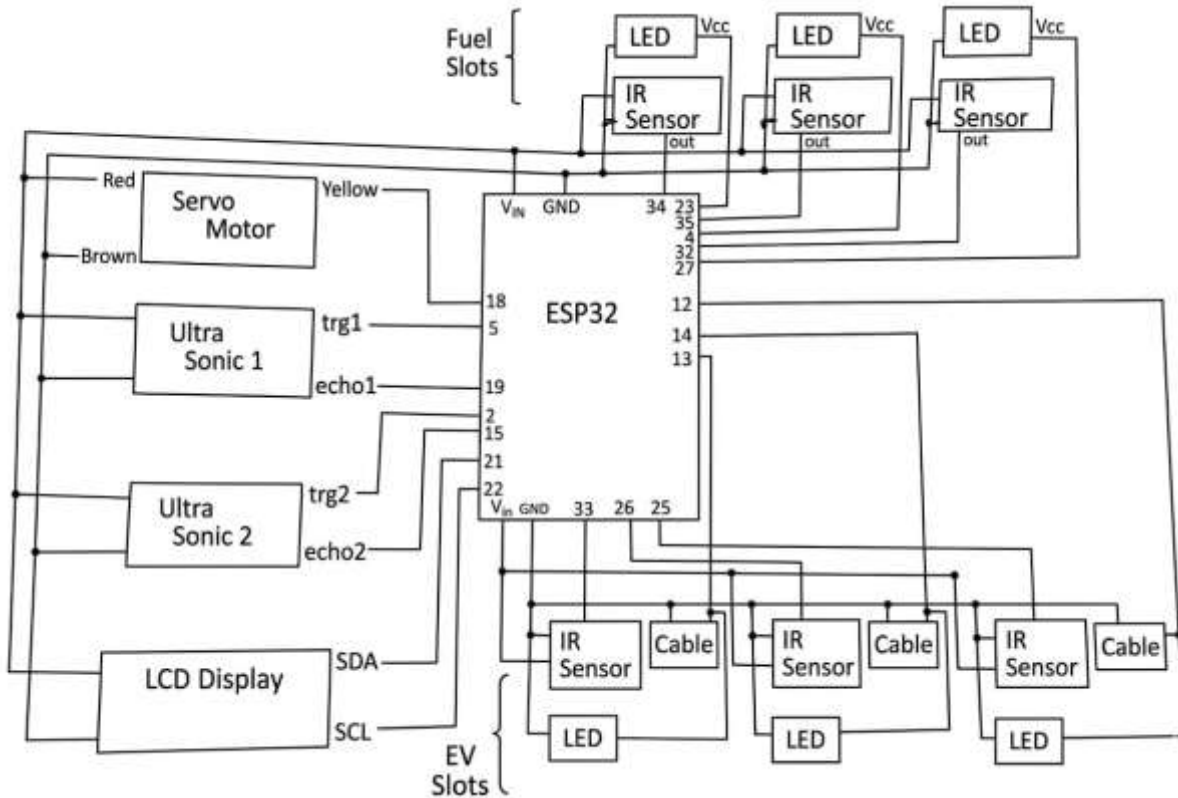


FIG 2: Circuit Diagram of Smart Parking system

3.2 SYSTEM WORKING

The operation of the smart parking system can be explained through several stages involving vehicle detection, slot monitoring, and gate control, as follows. The ESP32 microcontroller continuously reads data from the sensors and controls the connected devices accordingly. Initially, when a vehicle approaches the parking entrance, the first ultrasonic sensor placed near the gate detects the vehicle. Once the distance measured by the sensor fell within a predefined threshold, the ESP32 interpreted this as the arrival of a vehicle. The controller then sends a control signal to the servo motor, causing the gate to open.

After the vehicle passes through the gate, the second ultrasonic sensor positioned near the gate detects vehicle movement inside the parking area. When this sensor is triggered, the ESP32 commands the servo motor to close the gate. This ensures that the gate remains closed after each vehicle enters the parking lot.

Once inside the parking area, the driver parks the vehicle in any available slot. Each parking slot contains an infrared (IR) sensor that monitors the presence of a vehicles. When a vehicle occupies a slot, the IR sensor detects the obstruction and sends a signal to ESP32. In response, the corresponding LED indicator for that slot is turned on, indicating that the slot is currently occupied.

The ESP32 continuously checked the statuses of all six IR sensors installed in the parking area. Based on the sensor readings, the system calculates the number of parking slots available for fuel and electric vehicles. This information is then displayed on a 16×2 LCD screen so that users can quickly view the number of available spaces.

The system includes a simple charging demonstration for parking slots designated for electric vehicles. When the system detects that a vehicle is parked in an EV slot, the ESP32 activates a GPIO output connected to a charging wire. If the toy EV vehicle is connected to this wire, the LED installed inside the vehicle lights up, indicating that charging is in progress.

When a vehicle leaves a parking slot, the IR sensor does not detect the presence of the vehicle. Consequently, the ESP32 updated the slot status and decreases the occupied count. The LCD display was then refreshed to show the updated number of available parking spaces.

Finally, when a vehicle leaves the parking area, the second ultrasonic sensor near the exit gate detects the vehicle approaching it. The ESP32 then opened the gate by rotating the servo motor. After the vehicle passes through and the first ultrasonic sensor no longer detects it, the controller closes the gate. This completes the entry and exit cycle of the parking system. The working flow of the system is represented in Fig. 3.

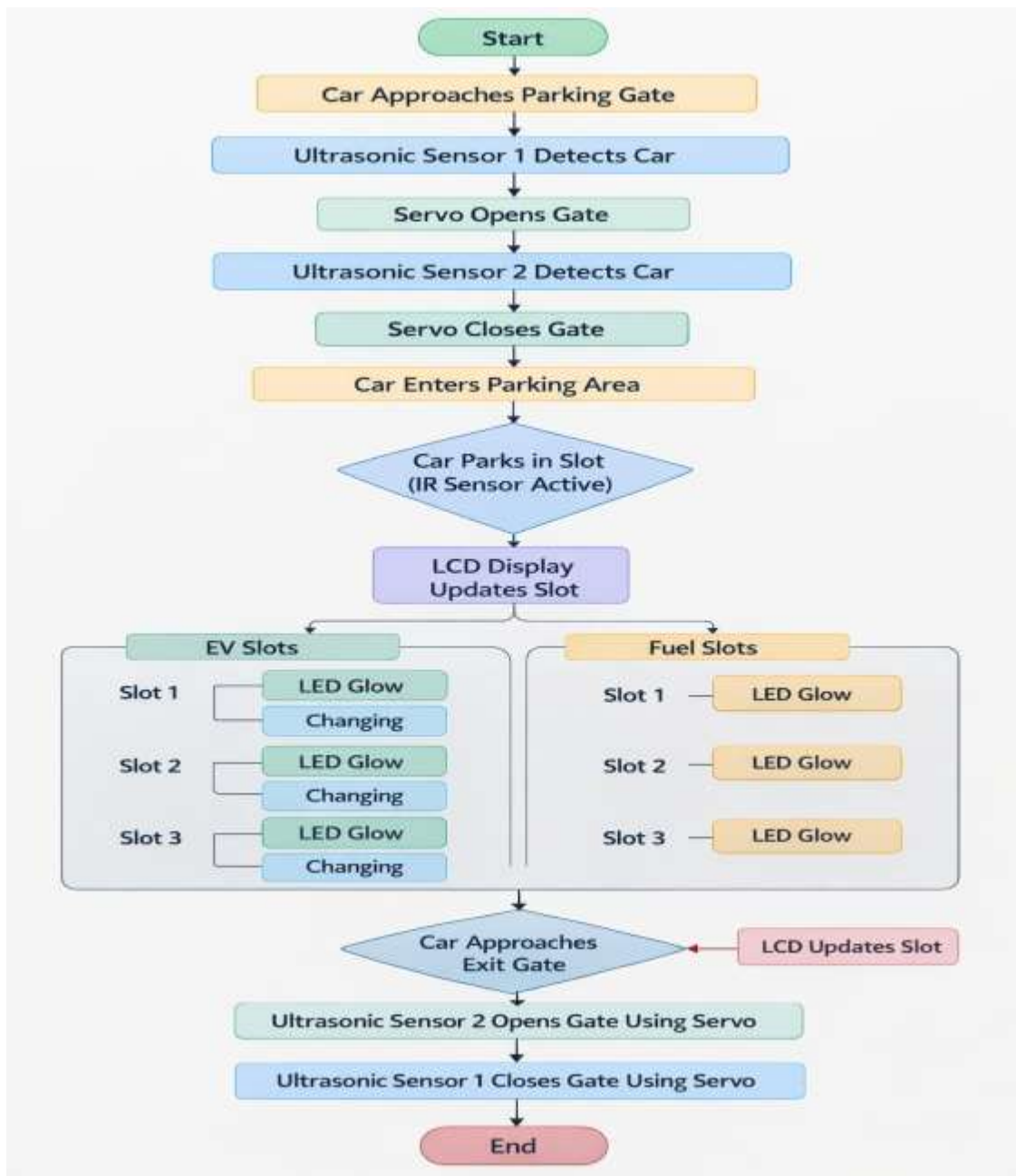


FIG 3: Working Flow Diagram of Smart Parking System

4. Results and Discussion

The developed prototype successfully demonstrated a coordinated approach to parking management and EV charging. During the testing phase, the system exhibited stable performance and high reliability across all automated functions.

4.1 System Performance Analysis

Gate Automation: The ultrasonic sensors accurately detected approaching vehicles, and the servo motor operated smoothly to manage entry and exit cycles.

Slot Monitoring: The IR sensors provided real-time feedback; when a vehicle was placed in a slot, the assigned LED turned on immediately, and the 16x2 LCD updated the vacant count for the correct category.

Charging Logic: The GPIO-controlled charging demonstration effectively simulated power delivery. When the toy EV was connected to the charging wire in an EV slot, the internal LED activated, proving that the ESP32 could successfully manage charging states based on slot occupancy.

4.2 Comparative Discussion

Unlike previous studies that focused on a single aspect, such as purely app-based monitoring or standalone charging stations, this project successfully integrates gate control, slot-specific monitoring, and charging infrastructure into one platform. While existing research notes that wireless charging efficiency can drop with misalignment, this prototype uses direct contact simulation to ensure a 100% success rate in power delivery for demonstration purposes.

4.3 Comparative Analysis of Output

To visualize how this project compares to standard smart parking systems described in the literature, the following comparison highlights the "Feature Integration Score." This score measures how many core features (Automation, Categorization, Real-time Feedback, and Charging) are combined in a single prototype.

Table: Feature Comparison Table

Feature	Standard Systems	This Project
Slot Detection	Yes	Yes
Automated Gate	No/Rare	Yes
EV vs Fuel Category	No	Yes
Integrated Charging	No	Yes
Microcontroller	Arduino Uno	ESP32

The implemented prototype of the smart parking system is shown in Fig. 4.

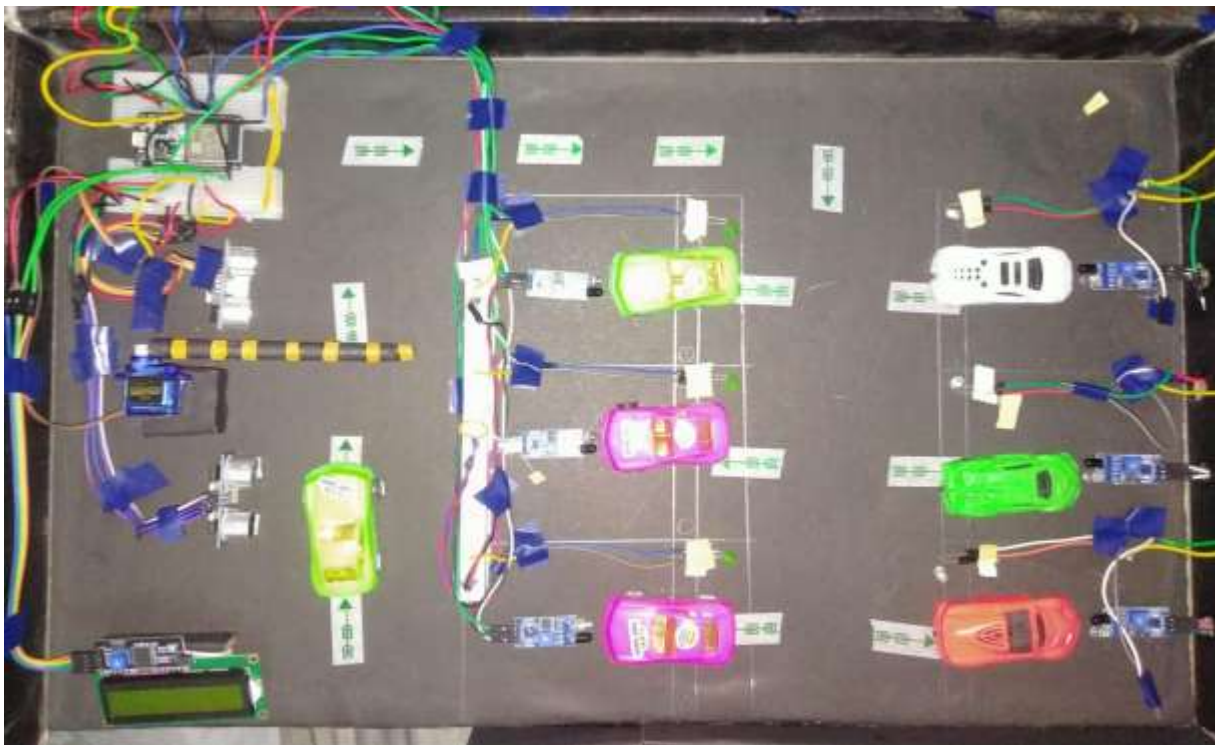


FIG 4: Prototype of the Smart Parking System

5. Conclusion

This study successfully presented the design and development of an integrated smart parking management system using an ESP32 microcontroller. The project achieved a high level of functional integration by combining automated vehicle entry and exit control with real-time slot monitoring and a proof of concept for electric vehicle charging. By utilizing ultrasonic sensors for gate automation and infrared sensors for individual slot detection, the system provides a reliable and cost-effective way to reduce traffic congestion and time wasted searching for parking.

A key contribution of this study is the categorization of parking slots into dedicated fuel and EV types, allowing the system to provide specific availability data via a 16x2 LCD display. Furthermore, the successful demonstration of a GPIO-controlled charging state proves that future smart parking infrastructure can seamlessly incorporate EV support to encourage sustainable transportation. Overall, this prototype offers a scalable and practical model for modern smart city applications, moving beyond the fragmented solutions found in previous research.

6. Future Scope

Although the current prototype successfully demonstrates the basic operation of a smart parking management system, several improvements can be considered in future developments to enhance its functionality and usability.

One possible enhancement is the integration of IoT platforms that would allow the remote monitoring of parking slot availability through the internet. By connecting the system to a cloud server or IoT dashboard, users and administrators can view parking information from remote locations.

Another improvement could involve developing a mobile application that provides real-time parking updates. Such applications can

display available parking slots, guide drivers to vacant spaces, and reduce the time spent searching for parking.

The system can also be extended by implementing automatic number plate recognition (ANPR). With the help of cameras and image processing techniques, vehicles entering and exiting the parking area can be automatically identified and recorded. This feature improves security and enables automated parking management.

In addition, future versions of the system may include real electric-vehicle charging stations instead of the current LED-based demonstration. Integrating appropriate EV charging modules would allow the parking system to support actual electric vehicles.

Finally, wireless communication between parking nodes can be introduced in larger parking facilities. In such a setup, multiple sensor nodes placed across different parking sections can communicate with a central controller or server, making the system scalable for large parking infrastructures.

7. Acknowledgement

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