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RFID-Based Secure Smart Parking System with Mobile Application Integration

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***Abstract*—With ever-growing urbanization and the increasing number of vehicles on the road, vehicle owners face significant challenges in finding parking spaces, ensuring security, and preventing theft. Considering the above, we have addressed all of these issues in this study and attempted to provide a solution. Using a mobile application, users can easily locate available parking spaces. The system features a servo motor-operated gate for authenticated entry, ultrasonic sensors to detect vehicles, and IR sensors to monitor the slot availability. RFID technology ensures secure exits, while a 16×2 LCD at the parking entrance displays slot status in real-time. Users can view the availability of parking spaces, register an authorized vehicle owner for reservation, and obtain a confirmed or canceled reservation via the mobile app. A unique feature of a smart parking slot is that a vehicle cannot exit the parking area without RFID verification. The implementation of the parking system involved a prototype with different slots, whose status could be accessed remotely through a mobile application.**

***Index Terms*—IoT, Smart Parking System, RFID, Mobile Application.**

I. Introduction

Parking has become a global issue around the world. Recently, millions of urban drivers have faced daily parking challenges, leading to wasted time, increased fuel consumption, greenhouse gas emissions, etc. [1]. Traditional parking systems face difficult issues in providing real-time information on slot availability, access control, and mechanisms of dynamic allocation [2] [3]. Therefore, these limitations frustrate the drivers, thus negatively impacting traffic congestion and environmental issues. Therefore, there is quite an urgent need to develop an innovative intelligent parking solution based on increased security, efficient space utilization, and enhanced users' convenience. Recent advances in IoT have enabled the integration of real-time data acquisition, automation of entry-exit mechanisms, and mobile-based user interfaces in smart parking solutions. However, most existing IoT-based parking systems still face challenges regarding their effectiveness in terms of cost, safety, and user experience. Many of these implemented applications either have inadequate security measures or do not support mobile app features for reservation and monitoring of parking spaces [4] [5]. To address these limitations, this paper proposes an "RFID-Based Secure Smart Parking System with Mobile Application Integration". The system uses ultrasonic sensors for vehicle detection, IR sensors for slot monitoring, RFID for secure exits, and a mobile app for booking, profile management, and real-time updates. A 16×2 LCD displays slot availability, while a proximity-based gate ensures secure access. The ESP32 microcontroller enhances system cost-effectiveness, security, and user-friendliness. This IoT-based solution effectively addresses modern parking challenges with improved technology and a user-friendly interface. The major contributions of this study are as follows.

- We studied the existing parking management solutions and developed a cost-efficient, user-friendly system.
- Our proposed system can detect slot availability using IR sensors.
- We introduced a mobile application that allows users to book slots, manage gate access, and view booking history, thereby improving their overall user experience.
- Finally, we demonstrated the performance of the proposed system through real-life simulations.

The remainder of this paper is organized as follows. Section II reviews recent IoT-based smart parking research. Section III describes the proposed system, including architecture, components, and workflow. Section IV presents experimental results and discussion. Finally, Section V concludes with a summary.

II. LITERATURE REVIEW

Owing to increasing vehicle density in urban areas, finding a smart solution for vehicle parking has become a significant challenge.Many researchers have conducted many studies and proposed IoT-based smart parking systems to solve the problem efficiently [6]. A parking system was proposed using IR sensors, ESP32, and servo motors, but they do not have any authentication system in their system. In [7], the authors presented a smart parking management system using slot monitoring, remote booking, RFID access, and cloud sync. They attempted to make the system efficient and secure, but the system was costly. In [8], the authors used a Raspberry Pi, IR sensors, a camera for vehicle detection, and license plate capture. Although the system was smart, no online booking system has been integrated. In [9], a touchless gate control system was developed using Arduino, ESP32-CAM, ultrasonic, and PIR sensors. However, the system has limitations, including sensor angle constraints and the absence of booking features. In [10], a system utilizing an ESP32 and ultrasonic sensors for monitoring and reservation was implemented, but there was a significant delay in their study. In [11], ESP32-CAM, various sensors, and a Raspberry Pi were

utilized for vehicle detection and license plate recognition, but the system was expensive. In [12], high implementation costs were incurred owing to the use of multiple sensors and controllers. In addition, there is a lack of safety after parking a vehicle.

In this study, we propose a system with multiple advanced features. Our system integrates real-time slot monitoring using IR sensors, an ultrasonic sensor with an authorized application for entry, and RFID technology for secure exit; mobile applications also include booking and managing parking slots. In addition, we included a 16×2 LCD for real-time status updates and proximity-based gate operations to enhance security and user convenience.

III. Proposed System

The smart parking system is designed to solve recent problems in urban parking management using advanced IoT technologies for real-time monitoring, secure access, and user-friendly applications. The block diagram of the system is shown in Figure 1.

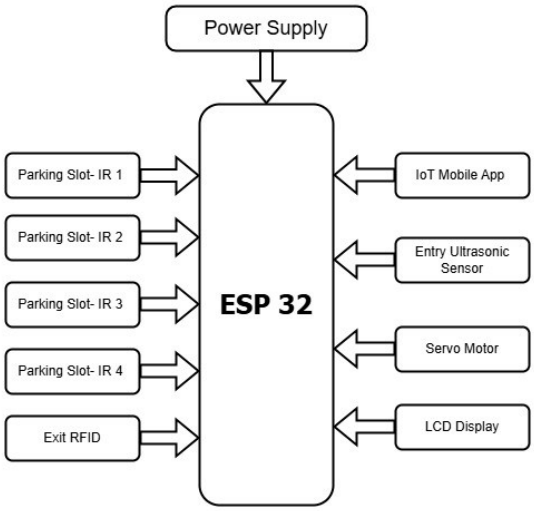

Fig. 1. System Block Diagram

The system uses a combination sensor, microcontrollers, and a mobile app for efficient parking management. IR sensors are used to detect vehicle presence in parking slots. An RFID module is used for secure exits, ensuring that only authenticated users can take their vehicle. A 16x2 is used for LCD displaying real-time slot availability. Additionally, a mobile application allows users to book parking slots, check slot availability, and manage gate operations.

A. System Components

The components used in the system are summarized below.

1) ESP32 Microcontroller: ESP32 is a microcontroller with built-in Wi-Fi and Bluetooth, which is ideal for IoT-based applications. It serves as the brain of the system and manages data from sensors, RFID modules, and mobile apps.

2) IR Sensors: These sensors were used to detect the presence of vehicles in parking spaces.

3) Ultrasonic Sensors: These sensors are used to detect the presence of vehicles at an entry point.

4) RFID Module: The RFID module ensures secure and authorized access to exit the parking members. Each parking slot is assigned a unique RFID card (e.g., Slot 1 has Card 1, Slot 2 has Card 2, and so on). When a user parks, their RFID card is linked to the specific slot. At the exit point, the system scans the RFID card associated with the slot to either grant or deny access based on the stored booking details. This system enhances security by ensuring that each parking spot is individually monitored.

5) LCD Display (16×2): A 16×2 LCD displays real-time parking slot availability at the facility, ensuring that users are informed of the available slots before entering.

6) Servo Motor: The servo motor controls the parking gate, allowing it to open or close in response to commands from the ESP32 microcontroller or mobile application.

7) Power Supply (7V Battery): The system is powered by a 7V battery, ensuring uninterrupted operation of the microcontroller and sensors.

8) Mobile Application: This mobile app enables users to book slots, check availability, and open gates using a proximity-based system. It also stores booking histories and user profiles for personalized interactions.

B. System Workflow

The workflow of the system is illustrated in Figure 2. The key operational steps are as follows:

1) Slot Monitoring: IR sensors are used to monitor slot availability. When a vehicle occupies or leaves a slot, it updates the slot status in real-time.

2) Booking and Availability Check: Users access a mobile application to view available slots. After selecting a slot, they proceed by the booking.

3) Proximity-Based Gate Control and Secure Exit via RFID: When a vehicle approaches the gate, an ultrasonic sensor detects its presence, and the mobile app automatically displays the “Gate Open” option for users with valid bookings. This proximity-based system ensures smooth and quick access. Upon exiting, users must scan their assigned RFID card to authenticate their departure, preventing unauthorized vehicles from leaving the parking area. Once the vehicle exits, the system updates the slot status to available, ensuring real-time parking slot management.

4) Real-Time Display: A 16×2 LCD at the gate displays the current slot availability for drivers who prefer not to use a mobile application.

5) User Interaction: The mobile app allows users to manage profiles, view booking history, and remotely control gate access.

This system integrates real-time monitoring, secure access control, and user-centric features, making it an efficient, scalable solution for modern urban parking management.

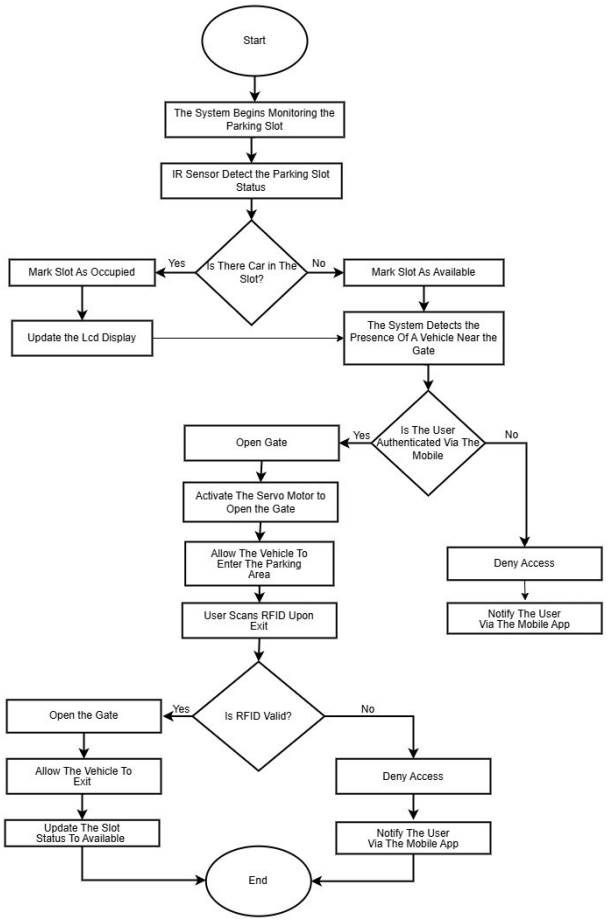

Fig. 2. Workflow of the Smart Parking System

The security of the parked vehicle is ensured by the RFID-based access control, which differentiates it from conventional parking systems.

IV. EXPERIMENTAL RESULT AND DISCUSSION

In this section, we present the experimental results obtained in a simulation environment. First, we discuss the experimental setup and then check the performance of the ultrasonic sensor for entry control, RFID system for exit management, and the overall functionality of the mobile app in real-time parking slot monitoring.

A. Simulation Environment

For experimentation, we have used the ESP32 as the project motherboard and connected different types of components. After connecting all the pieces of the component with ESP32, we uploaded a script to it and ran it to testing the device. The ESP32 was programmed using the Arduino IDE and the script was written in C++ to control the sensors. Figure 3 shows the RFID-Based Automated Parking System Model used for conducting the experiment.

Fig. 3. RFID-Based Automated Parking System Model

B. Result Analysis

In this section, we demonstrate the performance of the proposed device in terms of slot availability detection, entry and exit control, and mobile app responsiveness.

1) Slot Availability Detection: The IR sensor was tested for vehicle detection in parking spaces under various conditions, including different vehicle sizes and distances. Ten tests assessed its accuracy, with results shown in Figure 4.

Fig. 4. Slot Availability Detection Accuracy Across 10 Trials

2) Entry control performance: The ultrasonic sensor was tested for vehicle proximity detection at the entry gate. It successfully triggered the "Gate Open" button in the app, with response times summarized in Table I.

TABLE I
AVERAGE RESPONSE TIME OF THE MOBILE APP FOR DISPLAYING THE "GATE OPEN" BUTTON

Trial Number	Response Time (s)	Remarks
1	2.1	Successful
2	2.0	Successful
3	1.9	Successful
4	2.2	Successful
5	2.0	Successful
Average	**2.0**	**-**

3) Exit control functionality: The RFID-based vehicle exit system was tested by reading RFID cards at various distances and angles. Performance data is summarized in Table II.

TABLE II
EXIT CONTROL PERFORMANCE METRICS

Metric	Success Rate
Successful RFID Scans	98%
Unsuccessful RFID Scans	2%

4) Mobile App Responsiveness: The app was tested for real-time parking data updates and user interactions. It successfully reflected slot availability and allowed bookings with minimal delay, averaging a 3s update time. Figures 5 and 6 illustrate its performance and mobile app interface.

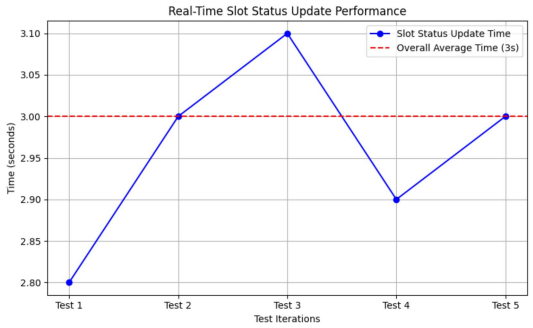

Fig. 5. Real-Time Slot Status Update Performance

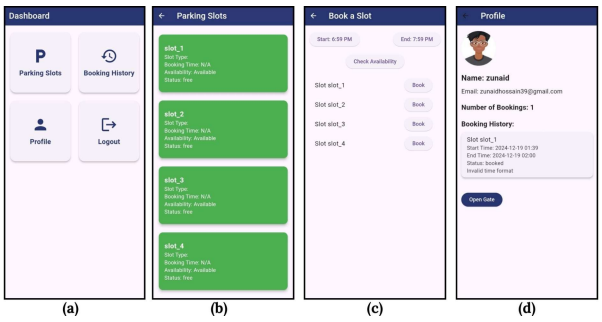

Fig. 6. Mobile App Interface: (a) Dashboard (b) Parking Slot Monitoring (c) Slot Booking (d) User Profile with Booking History and Gate Open Button

5) Cost of Materials: The system was designed to be cost-effective for easy prototyping and implementation. Table III summarizes the material costs, showing it is significantly more affordable than commercial parking solutions.

TABLE III
KEY COMPONENTS AND ESTIMATED COST

Component	Qty	Price (USD)
IR Sensor	4	4.00
Ultrasonic Sensor	1	1.00
RFID Reader	1	3.00
LCD 16x2	1	2.00
Servo Motor	1	5.00
ESP32	1	5.00
Battery	1	0.83
Total Cost	**-**	**21.66**

C. Comparison with other existing works

Table IV compares the proposed system with existing works based on key parameters such as technology used, security, authentication, booking system, reliability, processing speed, cost, and ease of implementation. The results highlight the proposed system's superior balance of high security, RFID-based authentication, mobile app integration, and cost-effectiveness, making it a highly efficient and reliable solution for smart parking.

TABLE IV
COMPARISON OF PROPOSED SCHEME WITH EXISTING SCHEMES

Features	[6]	[7]	[12]	Proposed Scheme
Technology	IR Sensors, ESP32	RFID, IR, Firebase	IoT, Mobile App	ESP32, RFID, IR, Ultrasonic, Mobile App
Security	Low	High	High	Very High
Authentication	No	RFID	No	RFID-Based
Booking	No	Yes	Yes	Yes (App)
Reliability	Medium	High	High	Very High
Processing	Medium	High	Medium	High
Cost	Low	High	High	Cost-Effective
Ease of Impl.	High	Medium	High	Medium

CONCLUSION

In this study, we introduced a smart parking system using IoT technology and the ESP32 microcontroller to address parking management challenges. Key features include real-time slot monitoring, ultrasonic sensors at entry, RFID-based exit control, and a mobile app for booking and live updates. The system optimizes space utilization and supports smart city initiatives. While effective in controlled conditions, challenges remain, such as IR sensor limitations in extreme weather. Future improvements will focus on enhancing scalability, refining the mobile app, and integrating computer vision or thermal sensors to differentiate vehicles from non-vehicle objects.

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