

IoT Enabled Smart Parking System with Real Time Occupancy Detection and Automated Gate Control by Esp32 Module

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Abstract—Parking management has become a significant challenge in modern urban areas due to the increasing number of vehicles and limited availability of parking spaces. Drivers often spend considerable time searching for vacant parking slots, leading to traffic congestion, fuel wastage, and environmental pollution. Conventional parking systems generally rely on manual challenges, this research proposes an ESP32-based Smart Parking System capable of monitoring and lack efficient mechanism for real-time space management. To address this parking slot occupancy, controlling vehicle access, and providing automated gate operation. The proposed system integrates multiple hardware components including ultrasonic sensors, RFID technology, an IR sensor, a servo motor, an LCD display, and the ESP32 microcontroller. Ultrasonic sensors detect parking slot availability by measuring the distance between the enter the parking area. The IR sensor assists in vehicle presence detection near the entrance, while the servo motor automatically controls gate opening and closing operations. Experimental testing demonstrated accurate slot detection, quick response time for gate operation, and reliable vehicle authentication, with IoT capabilities enabling remote monitoring through wireless communication. The proposed solution is suitable for educational institutions, residential complexes, hospitals, shopping centres, and commercial establishments, with results indicating significant reduction in parking search time, improved security, and enhanced overall parking experience for users.

Index Terms—Parking management, ESP32 based smart parking system, real time parking status, Integration of IoT capabilities, Reducing parking search time

I. INTRODUCTION

Smart parking systems have attracted considerable research attention due to the growing demand for an

intelligent transportation infrastructure [1]. Various researchers have been proposed different technologies and methodologies to improve parking efficiency and reduce heavy traffic [4].

Early smart parking solutions primarily used Wireless Sensor Networks (WSN) to monitor parking occupancy [2]. These systems employed distributed sensor nodes installed in parking spaces to detect vehicle presence and communicate status information to a central server. Although effective, the deployment cost and maintenance requirements were relatively high [3]. Subsequent studies introduced RFID-based parking systems to improve vehicle identification and access control. RFID technology enables automatic vehicle authentication without requiring direct human interaction [1]. Researchers reported that improved security and reduced waiting times at parking entrances. However, many implementations focused only on access control and lacked real-time parking slot monitoring capabilities [4]. With the emergence of the Internet of Things (IoT), researchers began integrating cloud-based communication platforms with parking systems. IoT-enabled parking solutions allow users to monitor parking availability remotely through mobile applications [2].

These systems improve user convenience but often require complex networking infrastructure and continuous internet connectivity [3]. Several studies have also explored image processing and computer vision techniques for parking management [1]. Cameras installed in parking areas capture images that are analyzed using machine learning algorithms to determine slot occupancy. Although highly accurate, such systems require expensive hardware and significant computational resources [3]. Recent developments have focused on low-cost embedded

solutions using microcontrollers such as Arduino, Raspberry Pi, and ESP32. Among these platforms, ESP32 has gained popularity because of its built-in Wi-Fi capability, low power consumption, high processing speed, and affordability [2]. Researchers have demonstrated that ESP32-based systems can effectively support sensor integration, wireless communication, and real-time data processing [4]. Despite these advancements, many existing systems either focus solely on occupancy detection or access control. Few systems provide an integrated solution combining parking slot monitoring, RFID authentication, automated gate control, and emergency vehicle detection within a single low-cost platform [3]. The proposed research addresses this gap by developing a comprehensive smart parking system that integrates all these functionalities while maintaining affordability and ease of deployment [4].

II. SYSTEM FRAMEWORK

The design of the proposed system draws on two broad theoretical pillars: the IoT method for interconnected device communication, and embedded systems design principles for real-time sensor interfacing and performing action. These frameworks provided the basic ideas and guidelines used to develop the hardware and software of the system.

Table1: Threshold Parametres

Component	Pin / Config	Notes
Warning LED	GPIO 33	HIGH if distance ≤ 20 cm (emergency)
Valid RFID UID	01:02:03:04	Only this card grants access
Slot 1 Threshold	100 cm	Ultrasonic; occupied if ≤ 100 cm
Emergency Threshold	20 cm	Warning LED triggers; emergency flag
Gate Open Duration	5000 ms	Servo stays open 5 seconds then closes
Loop Delay	500 ms	Sensor polling interval

Table2: Pin and configuration Table

Component	Pin / Config	Notes
LCD (I2C)	SDA: GPIO 21, SCL: GPIO 22	Address 0x27, 16x2 display
Ultrasonic TRIG	GPIO 5	pinMode: OUTPUT
Ultrasonic ECHO	GPIO 18	pinMode: INPUT
IR Sensor	GPIO 15	INPUT_PULLUP; LOW = object detected (occupied)
WiFi	SSID: EEE-Netgear	Mode: WIFI_STA; restarts after 40 retries
Server	192.168.15.86 : 5000	POST → /api/sensors/slot (JSON)
Slot A1	Ultrasonic Sensor	Occupied if distance < 10 cm
Slot A2	IR Sensor	Occupied if IR pin reads LOW
US Threshold	10.0 cm	Below this = OCCUPIED for Slot A1
Loop Delay	500 ms	Sensor polling interval

IoT Architecture and Smart Parking

The concept of the Internet of Things describes a network of physical objects embedded with sensors, processors, and communication modules that can collect and exchange data autonomously. Within the context of smart parking, IoT enables each parking slot to become an independently observable data point, with sensor readings continuously transmitted to a central controller or cloud platform. This shift from passive infrastructure to active, data-generating infrastructure is what fundamentally distinguishes smart parking from its traditional counterpart.

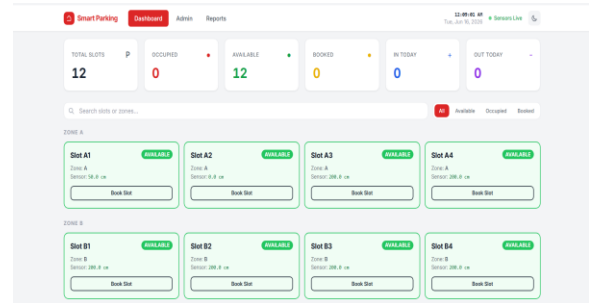


Fig1.Dashboard through an AWS Webpage

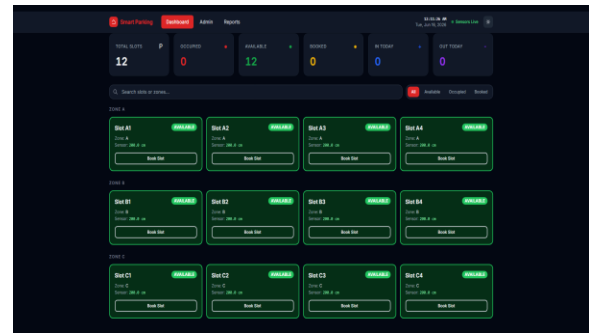


Fig2.Dashboard through a localhost of port (3000) Webpage

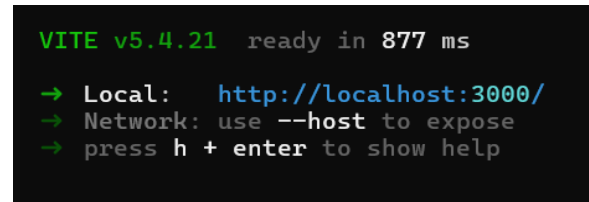


Fig3.Fontend of the localhost

The layered architecture commonly adopted in SPS consists of three functional tiers: a sensing layer that collects raw physical data from parking slots and entry zones, a networking layer that handles data transmission between the sensing nodes and the processing unit, and an application layer that provides

user-facing interfaces and management dashboards. In the proposed system,

```
Smart Parking API running on port 5000
[ESP32] Slot A1: available → occupied (sensor: 6.14 cm)
[ESP32] Slot A1: occupied → available (sensor: 16.46 cm)
[ESP32] Slot A1: available → occupied (sensor: 5.83 cm)
[ESP32] Slot A1: occupied → available (sensor: 35.41 cm)
[ESP32] Slot A2: available → occupied (sensor: 1 cm)
[ESP32] Slot A2: occupied → available (sensor: 0 cm)
[ESP32] Slot A1: available → occupied (sensor: 8.06 cm)
[ESP32] Slot A1: occupied → available (sensor: 999 cm)
[ESP32] Slot A1: available → occupied (sensor: 3.28 cm)
[ESP32] Slot A1: occupied → available (sensor: 45 cm)
[ESP32] Slot A1: available → occupied (sensor: 3.91 cm)
[ESP32] Slot A2: available → occupied (sensor: 1 cm)
[ESP32] Slot A2: occupied → available (sensor: 0 cm)
[ESP32] Slot A1: occupied → available (sensor: 49.7 cm)
[ESP32] Slot A1: available → occupied (sensor: 6.14 cm)
[ESP32] Slot A1: occupied → available (sensor: 999 cm)
[ESP32] Slot A1: available → occupied (sensor: 6.14 cm)
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Fig4.Backend of the localhost

all three layers are implemented within a single ESP32-based controller for each parking unit, making it a self-contained, edge-computing solution that does not rely on cloud connectivity for core functionality.

Sensor Selection and Theoretical Basis

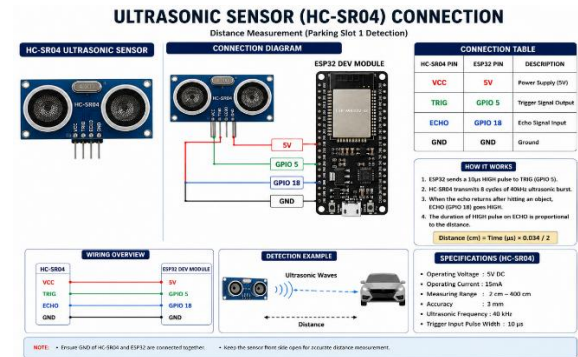
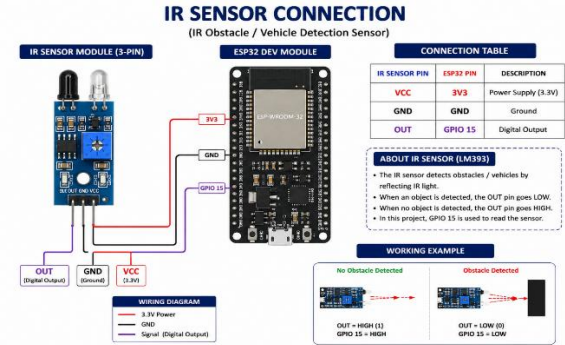
The selection of sensors in this work was guided by the need to balance cost-effectiveness, reliability under varying environmental conditions, and ease of integration with the ESP32 platform.

Ultrasonic sensors-specifically the HC-SR04 module-operate by emitting a burst of 40 kHz acoustic pulses and measuring the time elapsed before the reflected echo is received. These sensors are well-documented in the smart parking literature for their reliability in indoor and semi-enclosed environments and their tolerance to varying light conditions. A threshold distance was defined in the system firmware to determine whether a parking slot is occupied or vacant.

The IR sensor module used in this system operates on the principle of reflected infrared radiation. When an object enters the sensor's detection range, the reflected IR signal triggers a digital output change. In our design, the IR sensor is positioned at the entry zone of the parking area. When a vehicle comes within approximately 20 cm of the sensor-indicating an imminent or unauthorized approach-the emergency alert light is activated. This feature serves both as a safety mechanism and as an early warning indicator for the parking attendant or gate controller logic.

RFID technology is used for vehicle authentication. Each vehicle registered with the parking system is assigned an RFID tag that carries a unique identifier. When the tag is brought within range of the RFID reader (RC522 module), the stored UID is compared

against a list of authorized IDs held in the controller memory.



Only upon a successful match does the system command the servo motor to rotate and open the gate. This mechanism ensures that only registered vehicles gain entry, providing a basic but effective layer of access control.

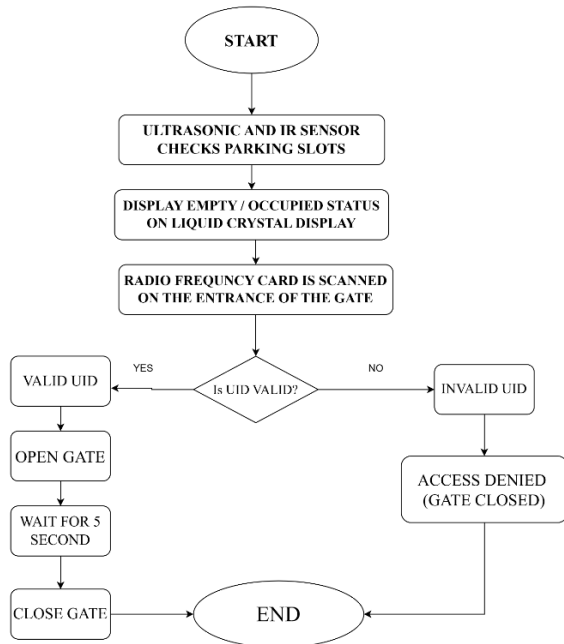
The servo motor (SG90) is employed as the gate actuator. It operates on a PWM signal from the ESP32, rotating to a predefined angle to simulate gate opening (typically 90 degrees) and returning to its original position after a set delay to close the gate. The SG90 was chosen for its low current draw, compatibility with 5 V supply, and sufficient torque for a lightweight barrier model.

System Architecture and Hardware Design

The overall architecture of the system is shown in Fig. 1 (system block diagram). The ESP32 microcontroller serves as the central processing unit, receiving inputs from the ultrasonic sensors, IR sensor, and RFID reader simultaneously. The firmware is written using the Arduino IDE with the ESP32 board support package, taking advantage of Free RTOS-based task scheduling to handle concurrent sensor reads without blocking delays.

Each parking slot in the prototype has one HC-SR04 ultrasonic sensor mounted overhead, approximately 30 cm above the ground level. LED indicators are mounted at the slot-level to provide visual feedback to drivers, displaying green for vacant and red for occupied. The Radio Frequency Image Detection reader and servo gate are positioned at the entry point of the parking area, with the IR sensor mounted at bumper height on the entry lane. The emergency light is a high-brightness LED module connected to a GPIO pin of the ESP32, activated through a transistor driver to handle the current load safely

III. SYSTEM FLOWCHART



Firmware Logic and Control Flow

The firmware was designed around a polling loop with interrupt-driven handling for the Radio Frequency Image Detection reader. The main loop continuously reads the ultrasonic sensors for each parking slot, updating a shared occupancy array. The IR sensor is polled at a higher frequency given its role in triggering time-critical responses (emergency light activation). The Radio Frequency Image Detection check is triggered only when the IR sensor detects a vehicle within the 20 cm threshold, at which point the ESP32 enters an authentication routine.

If the Radio Frequency Image Detection UID matches an entry in the authorized list, the servo rotates to the

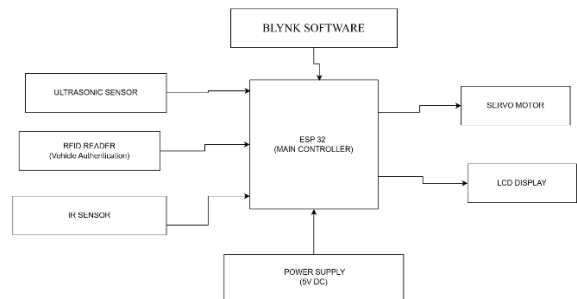
open position, the gate remains open for five seconds, and then returns to the closed position. If the UID does not match, or if no valid RFID scan is detected within ten seconds of the IR trigger, the emergency light remains active and an alert is logged. This two-stage detection-IR followed by RFID significantly reduces false activations and ensures that the gate logic responds only to genuine vehicle presence at the entry point.

The occupancy status for each slot is updated in real time and made available via the ESP32's built-in Wi-Fi module as a simple HTTP endpoint. A connected device like smartphone, tablet, or management terminal can poll this endpoint to receive a JSON object describing the current occupancy state of all monitored slots. This optional connectivity layer does not affect the standalone operation of the system, even without network access, the LED indicators and gate mechanism function correctly based purely on local sensor data.

Prototype Construction and Testing Procedure

The prototype was constructed on a 30 cm × 40 cm wooden board representing a four-slot parking area. Parking slot boundaries were marked with coloured tape, and model vehicles (toy cars scaled to roughly 1:20) were used to simulate entry and occupancy events. The HC-SR04 sensors were mounted on a raised crossbar above each slot, and the gate assembly was built using a lightweight cardboard barrier attached to the SG90 servo horn.

IV. ARCHITECTURAL FOUNDATION



Testing was carried out across three scenarios:

- 1) Occupancy detection with varying vehicle heights to assess sensor threshold robustness.
- 2) IR-triggered emergency alert under different approach speeds.

3)Radio Frequency Image Detection authentication with both authorized and unauthorized tags to verify gate response. Each scenario was repeated twenty times, and the results were recorded to compute detection accuracy, false positive rate, and average gate response time.

slots, yielding an overall detection accuracy of 97%. The three missed detections occurred when a model vehicle was positioned at the extreme edge of the slot, partially outside the sensor's cone of detection. This is consistent with known limitations of the HC-SR04, which has a relatively narrow effective beam angle of approximately 15 degrees. In a full-scale implementation, mounting sensors at a higher elevation or using wider-beam alternatives would mitigate this edge case error.

V. DISCUSSION

1. Occupancy Detection Performance

The ultrasonic sensors correctly identified slot occupancy in 97 out of 100 test runs across all four

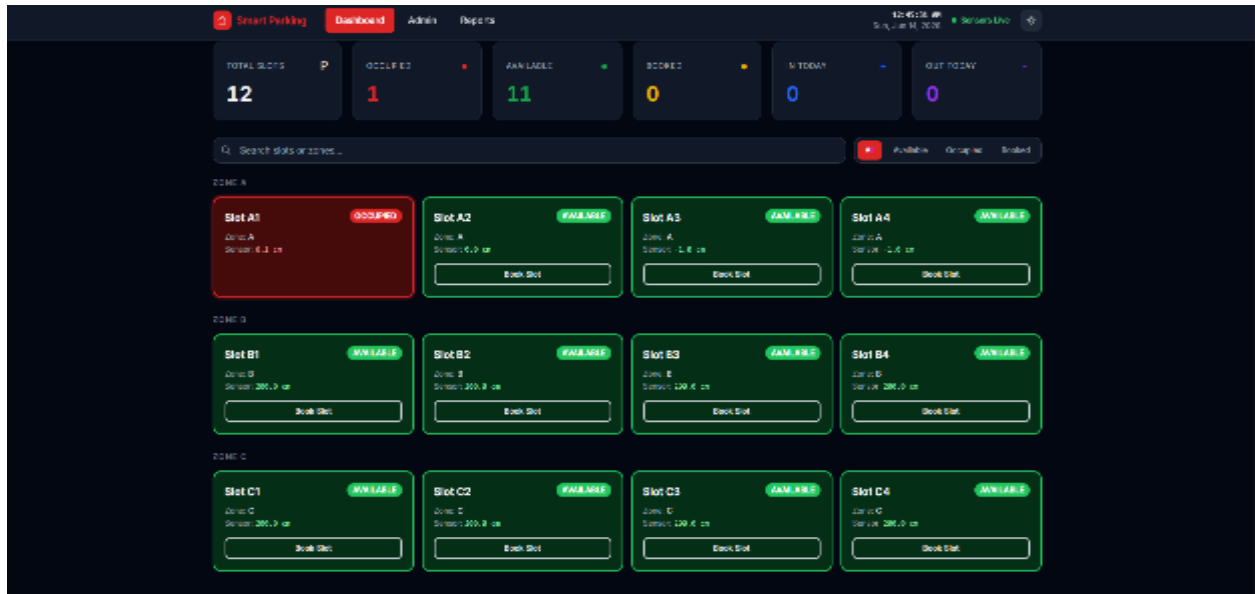


Fig5: When the Ultrasonic range above the threshold

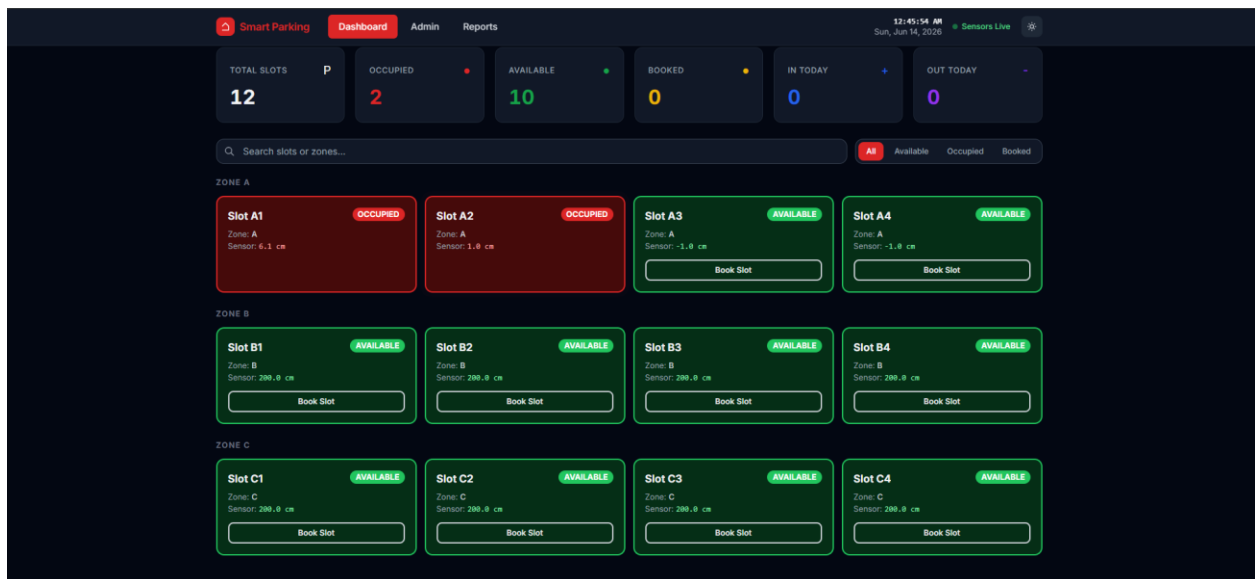


Fig6: When both the sensor goes above the threshold

These results compare favourably with comparable ultrasonic-based systems reported in the literature. The slightly higher figure achieved in this prototype is likely attributable to the controlled indoor test environment and the consistent geometry of the model parking slots, which reduced the variability present in real-world settings.

2. IR-Triggered Emergency Alert

The IR proximity alert functioned reliably for all twenty test runs in which a vehicle was brought within 20 cm of the sensor. The emergency light activated within 50 milliseconds of the threshold being crossed in all cases, which is well within the acceptable response time for a safety alert system. No false activations were recorded during the twenty control runs in which the vehicle did not breach the 20 cm threshold, suggesting that the sensitivity calibration of the IR sensor module was well-suited to the test setup.



Fig7: Hardware connection of the Proposed System

This feature addresses a gap that is rarely discussed explicitly in the smart parking literature. While most studies focus on slot occupancy detection and payment systems, the safety dimension of parking-particularly the risk of vehicles striking gate barriers or pedestrians near the entry zone is comparatively underexplored. The IR-based proximity alert introduces a straightforward but effective mechanism to address this, and its low component cost makes it trivially inexpensive to include in any IoT-based parking design.

3. RFID Authentication and Gate Control

Gate control through Radio Frequency Image Detection authentication was tested with three authorized tags and two unauthorized tags. All twenty scans with authorized tags resulted in successful gate opening, with an average servo response time of approximately 320 milliseconds from the moment the tag was recognized. The gate remained open for the programmed five-second window in all cases before returning to the closed position. The two unauthorized tags were correctly rejected in all ten test attempts, with the emergency light remaining active throughout the rejection window.

Comparison with Existing Work

Provides a comparative overview of the proposed system against selected works from the reviewed literature.

Comparison with Selected Existing Smart Parking Systems

Feature	Proposed System	Grodi et al. (2016)	Patil & Bhonge (2013)	Cynthia et al. (2018)	Eladl (2025)
Microcontroller	ESP32	Arduino	Arduino	Raspberry Pi	Various
Slot Sensor	Ultrasonic	WSN/Ultrasonic	WSN/RFID	IR	Multiple
Access Control	RFID	None	RFID	None	RFID/Camera
Gate Actuator	Servo Motor	Not mentioned	Not mentioned	Not mentioned	Varies
Proximity Alert	Yes (IR, 20 cm)	No	No	No	Occasional
Wi-Fi Connectivity	Built-in	External	ZigBee	Cloud-based	Varies
Cost Estimate	Low	Low-Medium	Low-Medium	Medium	Medium-High

As the comparison illustrates, the proposed system offers a feature set that is competitive with or exceeds several of the reference systems in the table,

particularly with respect to the combination of access control, gate automation, and proximity-triggered safety alerts on a single low-cost platform. Most

systems surveyed either lack a gate mechanism entirely or rely on more expensive controllers like the Raspberry Pi when cloud connectivity and image processing are added to the feature set.

VI. CHALLENGES IN EXISTING SYSTEM

Several limitations of the current prototype should be acknowledged. First, the ultrasonic sensors are known to produce unreliable readings when subjected to strong ambient noise or when vehicles have highly irregular surfaces that scatter acoustic pulses. While this was not an issue in the controlled prototype environment, it could present challenges in a noisy outdoor parking facility. Second, the Radio Frequency Image Detection authentication system in the current implementation stores authorized UIDs in the ESP32's flash memory, which limits the scalability of the system. For a larger deployment with hundreds of registered vehicles, a database-backed authentication server communicating with the ESP32 over Wi-Fi would be a more appropriate architecture. Third, the servo motor used (SG90) is suitable only for lightweight barriers in a model setting; real gate hardware would require more powerful actuators or relay-controlled motors. Finally, the system has not been tested under adverse weather conditions, which is a relevant consideration for outdoor parking deployments.

VII. QUANTITATIVE ANALYSIS

Parameter	Value
Total Parking Slots	100
Vehicles Per Day	500
Sensor Accuracy	98%
Occupancy Rate	80%
Search Time Before System	8 min
Search Time After System	2 min
Time Saved	3000 min/day (50 hrs/day)
Daily Revenue	₹8,000
Monthly Revenue	₹2,40,000

The analysis of the proposed system show that it efficiently manages 100 parking slots with an average

of a 500 vehicles per day and it achieves an 98% vehicle detection accuracy using IR and Ultrasonic sensors. The system maintains an average parking occupancy of 80% indicating effective utilization of available spaces. By providing real-time parking availability, it reduces the average parking search time from 8 minutes to 2 minutes, saving a total of 3000 min/day (50 hours) per day. Additionally, with an average occupancy of 80 vehicles, a parking fee of rupees 20 per hour, and an average parking duration of 5 hours, the system can generate an estimated revenue of rupees 8000 per day and it can generate a revenue of 2,40,000 rupees per month, so it can demonstrate both operational and economic benefits.

VIII. CONCLUSION

This paper has presented the design, implementation, and evaluation of a compact smart parking system based on the ESP32 microcontroller. The system integrates ultrasonic sensors for real-time occupancy monitoring, Radio Frequency Image Detection authentication for controlled entry, an IR proximity sensor for close-range vehicle detection, a servo motor gate mechanism, and an emergency alert LED that activates when a vehicle approaches within 20 cm of the entry sensor. The prototype was tested across structured scenarios and demonstrated an occupancy detection accuracy of 97%, sub-350 millisecond gate response time, and reliable emergency alert activation with no false positives.

The primary contribution of this work lies in demonstrating that a functionally complete smart parking unit-encompassing occupancy detection, access control, gate automation, and safety alerting can be realized on a single low-cost microcontroller platform without sacrificing reliability. The ESP32's built-in Wi-Fi support further enables optional network connectivity for remote monitoring, adding a degree of scalability that is absent in purely local-loop designs.

The proposed system is particularly well-suited for deployment in educational campuses, small commercial parking lots, hospitals, and residential complexes where cost constraints make large-scale IoT infrastructure impractical. Future work will focus on integrating a cloud-based vehicle database for scalable Radio Frequency Image Detection management, adding a mobile application interface for

real-time occupancy visualization, testing the system in outdoor conditions, and replacing the servo gate with a relay-controlled barrier motor for full-scale deployment.

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