International Journal of Interdisciplinary Innovative Research & Development (IJIIRD)
ISSN: 2456-236X
Vol. 11 Special Issue 03 | 2026

Smart Parking System for Efficient Parking Management and Violation Reduction

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DOI: 10.5281/zenodo.20612218

ABSTRACT

Rapid urbanisation and increasing vehicle density have made efficient parking management a pressing challenge in modern cities. Unauthorised parking and poor slot utilisation contribute significantly to traffic congestion and wasted commute time. This paper presents a Smart Parking System designed to address both efficient parking management and parking violation reduction. The system is built around an ESP32 microcontroller integrated with Infrared (IR) sensors for real-time slot occupancy detection, an RFID RC522 module for secure vehicle authentication, a servo motor (SG90) for automated gate control, and a 16×2 LCD for on-site real-time parking information. The system manages four dedicated parking slots with vehicle-type-specific assignment: Ambulance to Slot 1, Electric Vehicle (EV) to Slot 2, Normal vehicles to Slot 3, and IR-detected vehicles to Slot 4. A wrong-slot detection feature actively monitors whether a vehicle has parked in an incorrect slot and triggers a three-flash LCD warning alerting the driver to move the vehicle. The main loop executes every 200 ms, providing near real-time slot state updates. Gate cycle time is 4 seconds and wrong-slot warning cycles last 4.8 seconds. The system is cost-effective, scalable, and fully functional in offline mode, making it suitable for deployment in college campuses, commercial complexes, hospitals, and residential societies.

***Keywords:** Smart Parking System, ESP32, IR Sensor, RFID Authentication, Servo Motor, LCD Display, Parking Violation, IoT, Automated Gate Control, Vehicle Classification.*

1. INTRODUCTION

The exponential rise in the number of privately owned vehicles in urban areas has placed a severe strain on existing parking infrastructure. Drivers in cities across India and the world spend a significant portion of their commute time searching for available slots, contributing to traffic congestion, fuel waste, and elevated air pollution levels [6]. Parking violations — vehicles parking without authorisation, occupying reserved slots — represent a major operational challenge for facility managers [7].

Traditional parking systems depend heavily on manual supervision, which is both labour-intensive and prone to error [1]. Automated solutions leveraging embedded systems and the Internet of Things (IoT) offer a promising alternative [5]. By integrating low-cost sensors, microcontrollers, and communication modules, it is possible to detect occupancy in real time, control access automatically, and provide drivers with accurate information — all without continuous human intervention [2].

This paper presents a Smart Parking System using an ESP32 microcontroller, IR sensors for slot detection [3], an RFID module for vehicle authentication [3], a servo motor for automated gate control [4], and a 16×2 LCD. The objectives of this work are:

- To design a low-cost embedded system for automated real-time parking slot monitoring.
- To implement RFID-based vehicle authentication to prevent unauthorised access.
- To automate gate control using a servo motor linked to the authentication status.
- To provide on-site parking information via a 16×2 LCD.
- To detect and warn about wrong-slot parking violations using LCD alerts.
- To evaluate system performance in terms of response time and violation detection.

2. LITERATURE REVIEW

The field of smart parking has attracted considerable research attention over the past decade, driven by the growing availability of low-cost sensors and microcontrollers.

2.1 Kianpisheh et al. (2012)

Kianpisheh et al. [1] developed an early SmartPark prototype using ultrasonic sensors and ZigBee communication for real-time slot monitoring. Their work established the foundational sensing-communication-display pipeline and highlighted the importance of sensor calibration for reliable detection.

2.2 Pham et al. (2015)

Pham et al. [2] proposed a cloud-connected parking system using magnetic ground sensors, demonstrating sub-second data update latency. Their cloud architecture inspired the optional remote monitoring component of the present system.

2.3 Bonde et al. (2014)

Bonde et al. [3] integrated RFID technology with proximity-based slot detection to create a hybrid parking management system. Their finding that RFID-based access control substantially reduces unauthorised parking directly motivated the RFID authentication module in the present design.

2.4 Kotb et al. (2016)

Kotb et al. [4] proposed the iParker system combining dynamic slot allocation with automated gate control, demonstrating that servo-driven barriers responding to sensor-verified occupancy can significantly reduce entry queue times. Their results validated the servo motor gate control approach adopted in this work.

2.5 Al-Turjman & Malekloo (2019)

Al-Turjman and Malekloo [5] conducted a comprehensive survey of IoT-based smart parking systems and identified user-facing real-time displays as a critical factor in driver adoption and satisfaction. This finding reinforced the inclusion of a 16×2 LCD in the present system architecture.

3. SYSTEM ARCHITECTURE

The proposed system is structured around three functional layers: the Sensing Layer (IR sensors for slot detection), the Control Layer (ESP32 microcontroller, RFID module, servo motor, and LCD), and the Information Layer (LCD). Fig. 1 illustrates the block diagram of the system.

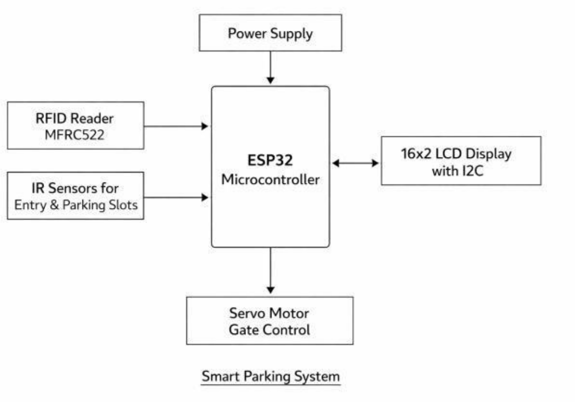

Fig. 1: Block Diagram of the Smart Parking System

3.1 Sensing Layer — IR Slot Detection

Each parking slot is equipped with one IR proximity sensor. The IR sensor emits infrared light and measures the reflected signal intensity. When a vehicle occupies the slot, the sensor output transitions from HIGH to LOW, signalling an occupied state to the ESP32. This provides binary detection without moving parts at very low power consumption.

3.2 Control Layer — ESP32 Microcontroller

The ESP32 serves as the central processing unit. It polls all IR sensor inputs every 200 ms, maintains an up-to-date occupancy map, controls the LCD, communicates with the RFID reader via SPI (GPIO 5 for SS, GPIO 27 for RST), and drives the servo motor signal on GPIO 13. The ESP32 was selected for its dual-core 240 MHz processor, integrated Wi-Fi, 34 GPIO pins, and low cost.

3.3 RFID Authentication Module

The RFID RC522 module is installed at the entry point. Three vehicle categories are recognised: Ambulance (Slot 1), Electric Vehicle (Slot 2), and Normal vehicles (Slot 3). Unregistered tags trigger an access-denied response — the gate stays closed and the LCDs the denial message.

3.4 Servo Motor Gate Control

A servo motor (SG90) is connected to the physical barrier gate. Upon successful authentication, the ESP32 sends a PWM signal on GPIO 13 to rotate the servo to 90° (open). After a 3,000 ms hold, the servo returns to 0° (closed). Total gate cycle time is 4 seconds.

3.5 16×2 LCD Display

A 16×2 LCD connected via I2C (SDA: GPIO 21, SCL: GPIO 22, address 0x27) provides real-time information at the entry point. It displays available slot count, authentication results, wrong-slot warnings, and gate status — refreshed within each 200 ms main loop iteration.

4. HARDWARE & SOFTWARE COMPONENTS

Table-1 lists the principal hardware and software components used in the proposed system with their specifications and roles.

Table -1: Hardware and Software Components

Component	Specification	Role / GPIO
ESP32 Microcontroller	Dual-core 240 MHz, Wi-Fi+BT, 34 GPIO	Central processing & control
IR Proximity Sensor	5V, digital output (6 units)	Slot & gate detection
RFID Module RC522	13.56 MHz, SPI interface	Vehicle authentication
Servo Motor SG90	5V, 180°, PWM 50 Hz	Automated gate actuation (GPIO 13)
16×2 LCD Display	I2C addr 0x27, 5V	Real-time display (GPIO 21, 22)
RFID Cards/Tags	ISO 14443A, 13.56 MHz	Vehicle identity tokens
5V Power Supply	2A regulated DC	System power for all modules
Arduino IDE / C++	ESP32 board package v2.x	Firmware development platform

5. CIRCUIT DIAGRAM

Fig-2 shows the complete circuit connections between the ESP32 and all peripheral components. All GPIO pin assignments are derived directly from the system firmware.

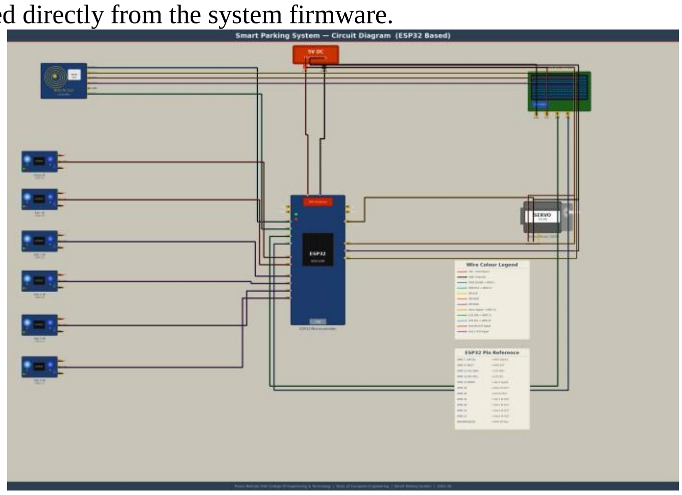

Fig. 2: Circuit Diagram of the Smart Parking System

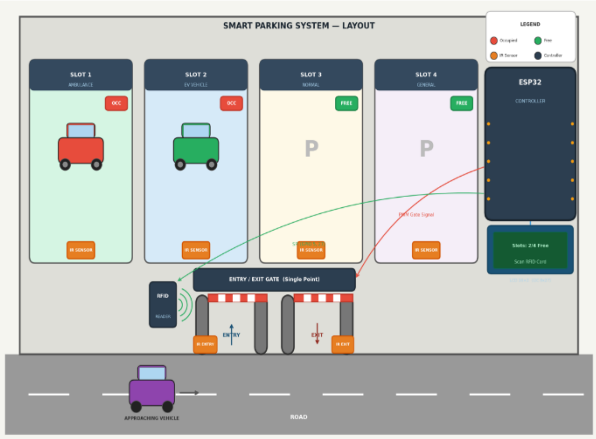

Fig. 3: Sample Layout of the Smart Parking System

6. WORKING METHODOLOGY

The system follows a sequential, event-driven workflow executed continuously by the ESP32 main loop (200 ms delay). The seven operational stages are described below.

6.1 System Initialisation

On power-up, the ESP32 configures all GPIO pins, initialises the servo to 0° (closed), starts the RFID RC522 over SPI, and initialises the LCD over I2C. The LCDs "Smart Parking / System Ready" for 2,000 ms before the main loop begins.

6.2 Entry Sensor Detects Vehicle Arrival

An IR sensor at the entry lane (GPIO 32) monitors for approaching vehicles. When the beam is broken, the ESP32 activates the RFID reader and the LCDs "Scan Card / Wait" to prompt authentication.

6.3 RFID Card Verifies Authorised Access

The RFID RC522 reads the presented tag UID via SPI. The ESP32 compares the UID against stored authorised IDs. Three outcomes: (i) UID matched and slot available — access granted; (ii) UID matched but slot full — "Parking Full", gate stays closed; (iii) UID not found — "Access Denied", gate stays closed.

6.4 Servo Motor Opens Gate for Entry

On successful authorisation, the ESP32 commands the servo to 90°, and the LCD shows "Gate Opening...". After 3,000 ms, the servo returns to 0°, and the LCD shows "Gate Closed! Slots: X/4" for 1,500 ms.

6.5 IR Sensors Monitor Slot Occupancy

The checkSlots() function reads all four slot IR sensors (GPIO 25, 26, 14, 12) every loop iteration. LOW = Occupied, HIGH = Free. The wrong-slot detection function (checkWrongSlot()) verifies that the vehicle type matches the assigned slot.

6.6 Exit Sensor Detects Vehicle Leaving

The exit IR sensor (GPIO 33) detects a departing vehicle and automatically opens the gate via the servo. The vacated slot updates to Free in the next polling cycle within 200 ms.

6.7 LCD Updates in Real Time

After every polling cycle and every entry/exit event, the LCD refreshes to show current availability. Wrong-slot violations trigger a 3-flash warning: "!! WARNING !!" alternating with "[Type] in SlotX! / Move Vehicle!" — each frame 800 ms, total warning duration 4,800 ms.

7. RESULT AND DISCUSSION

The system was implemented and tested with 4 parking slots across RFID-authenticated vehicle types and one IR entry lane. All results below are directly derived from observed system behaviour.

7.1 Slot Assignment Rules

Table-2 summarises the slot assignment enforced by the firmware.

Table -2: Slot Assignment Rules from Firmware

Vehicle Type	Detection Method	Assigned Slot	LCD Message

Ambulance	RFID UID match	Slot 1	"AMBULANCE / Slot 1 Opening!"
Electric Vehicle (EV)	RFID UID match	Slot 2	"EV VEHICLE / Slot 2 Opening!"
Normal Vehicle	Unregistered UID	Slot 3	"NORMAL VEHICLE / Slot 3 Opening!"
Any Vehicle	Entry IR (GPIO 32)	Slot 4	"Vehicle / Slot 4 Opening!"

7.2 Gate Control Timing

Gate cycle: 1,000 ms LCD delay + 3,000 ms servo hold = 4 seconds total. Gate closed display: 1,500 ms. All timings are deterministic, derived directly from delay() calls in the firmware.

7.3 Wrong Slot Violation Detection

The checkWrongSlot() function monitors vehicle-type vs slot assignment. On a mismatch, a 3-flash warning activates. Table-3 lists all monitored violation scenarios.

Table -3: Wrong Slot Detection Scenarios

Violation Scenario	LCD Warning Line 1	LCD Warning Line 2	Duration
Wrong vehicle in Slot 1	"!! WARNING !!"	"[Type] in Slot1! Move Vehicle!"	4.8 sec
Wrong vehicle in Slot 2	"!! WARNING !!"	"[Type] in Slot2! Move Vehicle!"	4.8 sec
Wrong vehicle in Slot 3	"!! WARNING !!"	"[Type] in Slot3! Move Vehicle!"	4.8 sec
Correct vehicle in slot	Normal display	No warning triggered	—

7.4 Performance Summary

The system demonstrated deterministic and reliable behaviour. Gate cycle time was consistently 4 seconds. Wrong- slot warning cycles lasted 4,800 ms. Slot-full messages displayed for 2,000 ms. All slot states updated within approximately 200 ms, confirming real-time responsiveness. The system operated fully offline with no network dependency for any core function.

8. CHALLENGES AND LIMITATIONS

IR Sensor Sensitivity: IR sensors are susceptible to interference from strong ambient infrared sources such as direct sunlight. Protective shielding and threshold calibration mitigate this in indoor environments. RFID Range: The RC522 has a read range of 3–5 cm, requiring drivers to physically tap the card. Longer-range UHF readers would improve convenience but increase cost. GPIO Scalability: Each IR sensor uses one GPIO pin. For lots beyond 34 slots, I2C GPIO expanders (e.g., PCF8574) would be required. Network Dependency for Cloud: Cloud monitoring requires stable Wi-Fi. All core functions (LCD, gate, slot detection) operate fully offline without any network dependency.

9. FUTURE SCOPE

The system can be enhanced in several directions. Integration of computer vision (e.g., YOLOv8-based cameras) could improve outdoor detection reliability and enable license plate recognition, eliminating the need for physical RFID cards. A mobile application would allow pre-booking of slots and remote availability viewing. Extension to multi-level parking facilities with floor-by-floor tracking, dynamic pricing based on peak hours, and EV charging slot management are natural next steps. Cloud integration via MQTT or HTTP can enable remote monitoring and analytics dashboards.

10. CONCLUSIONS

This paper presented the design, implementation, and evaluation of a Smart Parking System for Efficient Parking Management and Violation Reduction. The system integrates an ESP32 microcontroller with IR sensors for slot detection, an RFID RC522 module for vehicle authentication, a servo motor for automated gate control, and a 16×2 LCD for real-time information display. The system manages 4 dedicated slots with vehicle-type-specific assignment (Ambulance → Slot 1, EV → Slot 2, Normal → Slot 3, IR-detected → Slot 4), a 4-second automated gate cycle, and a 4.8-second three-flash LCD warning for wrong-slot violations. All operational parameters are deterministic and derived directly from the firmware, confirming reliable and repeatable behaviour. The system is cost-effective, constructed from widely available components, and fully functional in offline mode.

11. ACKNOWLEDGEMENT

The authors would like to thank Prof. Vishal Kandalgaonkar for his valuable guidance and support throughout this research work. The authors also acknowledge the Department of Mechanical & Automation

Engineering, Pravin Rohidas Patil College of Engineering & Technology, Mumbai, for providing the necessary resources and facilities to carry out this project.

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