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Smart RFID-Based Automated Car Parking System: A Technological Leap in Urban Mobility

Ahmed Hatem Ahmed[1], Archana Chaudhari[2]
Department of Instrumentation Engineering Vishwakarma Institute of Technology Pune,India

Abstract*: The paper presents the design and deployment of an intelligent RFID-based car parking system to address the inefficiencies of traditional parking infrastructure. Based on Radio Frequency Identification (RFID) technology, the system enables automatic vehicle identification, real-time tracking, and secure access control without human intervention. The system architecture consists of RFID readers, S50 RFID cards, a microcontroller-based control system, and motorized barriers. Simulation and field tests indicate space utilization improvement, waiting time reduction, and improved user convenience. The paper also presents the system's possible extension to intelligent city programs and electric vehicle (EV) charging stations, which makes it a future-vision solution to urban mobility challenges.
Keywords: RFID, Smart Parking, IoT, Automation, Real-time Monitoring, Urban Mobility.

I. INTRODUCTION

The boom of mass urbanization and car ownership has placed phenomenal pressure on available parking facilities, resulting in typical issues like traffic congestion, space wastage, lengthy waiting periods, and human errors with manual ticketing. Traditional parking systems, which are usually based on human operation and antiquated mechanisms, are not capable of meeting the requirements of contemporary urban centers.

To counter the drawbacks, the present paper proposes an RFID-based smart car parking system based on automation for the optimization of parking procedures. Radio Frequency Identification (RFID) technology, widely applied for identification and tracing, is the core of the system. RFID tags attached to vehicles communicate with optimally positioned readers at entry and exit points, facilitating ease of vehicle identification, automatic gate management, and real-time parking information management.

By integrating RFID hardware and centralized management, the solution increases operating efficiency, reduces human error, and improves overall user experience. The system offers the potential for a basis for future integration with intelligent transport systems, intelligent payment systems, and other intelligent city solutions.

II. LITERATURE REVIEW

A number of research studies have researched the incorporation of RFID technology in car parking systems and demonstrated that it can address the shortcomings of traditional parking systems.

Prabakaran, Baskaran, and Rajendran (2016) developed an RFID-based automated car parking system utilizing passive RFID tags and entry/exit readers with significant advancements in automation and operational effectiveness. Likewise, Soni (2017) developed and designed an RFID-based car parking system with emphasis on real-time access control, automation, and low intervention.

Scaling up, Mainetti et al. (2014) proposed a Smart Parking System (SPS) that combines RFID and Wireless Sensor Networks (WSNs) to provide real-time information regarding parking space availability. The system also includes a mobile application, offering dynamic navigation support and space reservation services.

In another new research work, Salah (2020) suggested an RFID-based autonomous parking system using a robotic arm for car handling. By simulation and performance analysis, the paper demonstrated the system to be extremely accurate, efficient, and effective under various traffic conditions.

Cho, Kim, and Shin (2019) analyzed an extensive RFID-based parking management system, such as RFID readers, CCTV cameras, and barriers to enable access control and security. Enhanced cost-effectiveness and parking management through centralized data control were highlighted in their research.

Yadav (2014) was interested in practical implementation of RFID-based parking systems, their utilization in automating entry, improving space monitoring, and reducing waiting time. Li and Zhu (2018) also proposed an RFID-based parking lot management system to facilitate easy entry/exit operations, reduce human effort, and streamline parking operations.

Further research by More, Ravariya, Shah, and Solkar (2017) emphasized the advantages of automating using RFID tags for secure and easy car parking systems. Such collaborative research forms the foundation for future smart parking system innovations and enables the creation of scalable, real-time systems with in-built wider smart city programs.

III. SYSTEM COMPONENTS

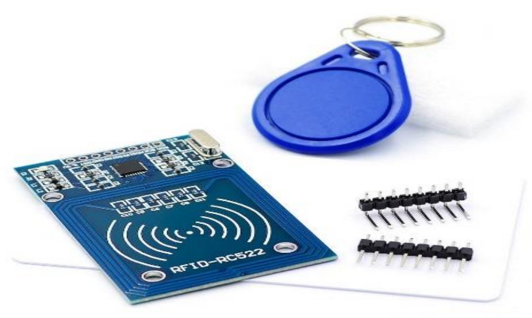
The main operation of the RFID-based automatic car parking system is through a series of hardware devices including each component being responsible for real-time monitoring, identification, and gate control functions. The following is a clear description of the primary components utilized:

A. MFRC-522 RFID Reader Module

MFRC-522 is a widely used RFID reader/writer module at 13.56 MHz and based on the ISO/IEC 14443A standard. It can read and write information from various RFID cards, particularly MIFARE cards. It is capable of seamless integration with microcontrollers via SPI communication and has a built-in antenna for contactless data transfer. It senses and authenticates RFID tags in entry and exit processes.

B. S50 RFID Card (Fudan Card)

The S50 RFID card is a contactless smart card that is designed on the MIFARE Classic 1K chip. It is powered at 13.56 MHz and offers 1 kilobyte of storage capacity, which is divided into sectors and blocks to hold data. It is utilized widely in access control systems due to its secure communication protocol and simple implementation. In the parking system, each vehicle is equipped with an S50 card to identify it.



C. NodeMCU(ESP8266)

NodeMCU is an open-source microcontroller board developed on the ESP8266 Wi-Fi SoC. It integrates microcontroller capabilities with in-built Wi-Fi support for IoT applications. It is programmed by Arduino IDE using Lua or C/C++ programming language. It provides various digital I/Os, SPI, I2C, UART serial communication interfaces and is run at clock speeds of 80–160 MHz.

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In this parking system, NodeMCU acts as the central controller which:

1) Talks to MFRC-522 RFID reader via SPI protocol.
2) Controls the gate travel servo motor.
3) Transmits live parking data to a cloud server or a centralized database via Wi-Fi.
4) Offers remote monitoring, logging, and control through web-based dashboards or mobile apps.

NodeMCU's compactness, affordability, and Wi-Fi capability make it a superior option over Arduino Uno for large-scale deployments and smart city applications.

D. Servo Motor

A servo motor is utilized for gate mechanism control in the parking system. It provides precise angular motion through internal feedback mechanisms. The servo receives control commands from the NodeMCU and adjusts the gate position based on that—opens on the presentation of a valid RFID card and closes on the vehicle's passage. Its precision and speed make it best for controlled barrier automation. Each of those components is necessary to get the system running securely, smoothly, and reliably.

IV. METHODOLOGY

Installation of an RFID-based automated car parking system is a well-designed process with software and hardware integration. The process is designed so that the system achieves objectives including traffic alleviation, user facilitation, safety, and vehicle tracking in real-time. The major stages include:

A. Requirement Analysis

A detailed analysis of the parking facility needs is conducted to determine system objectives like space usage, degree of automation, traffic capacity, and integration requirements. Significant problems like peak-hour jams, delays caused by manual processing, and security violations are determined.

B. System Design

According to the specifications, a system architecture is created. This includes:

1) Installation of RFID readers at entry and exit points.
2) Communication flow from the hardware to the centralized server.
3) Database schema for storing data regarding users and cars.
4) Real-time gate control logic and data synchronization control.

C. RFID Reader Installation

RFID readers (MFRC-522 modules) are placed at strategic points such as:

1) Entrance gates
2) Exit gates
3) Optional stopping places within the building

The readers are set for proper tag identification and connected with the microcontrollers for processing and transmission.

D. Centralized Control System Development

The control system regulates:

1) User authentication by RFID tag IDs.
2) Gate access control by servo motor control.
3) Storage of time-stamped data such as entry/exit logs.
4) Admin reporting and monitoring interface.

It also maintains a database to hold tag-user relationships, transaction records, and occupancy information.

E. Integration with Payment Systems and Entry/Exit Terminals

Servo motors are used with boom barriers or gates. Such motors are energized according to valid RFID scans. Voluntarily, the system may be paired with electronic payment gateways or wallets for automatic billing and cashless parking fee payments.

F. Testing and Evaluation

Mass testing is conducted under various conditions:

1) Tag detection accuracy
2) Response time at entry/exit points
3) Traffic carrying capacity
4) System stability and error handling

The important performance metrics such as read success rate, time saved per transaction, and user satisfaction are monitored.

G. Deployment and Training

After the successful test, the system is deployed in the parking lot. Operators and staff are trained on how to operate daily, resolve minor problems, and utilize the admin dashboard effectively. 6.8 Monitoring and Ongoing Improvement After deployment, the system is constantly monitored. User and operator feedback is gathered to determine where improvements can be made. Software patches, performance tuning, and hardware upgrades are implemented as necessary to ensure efficiency and scalability. This step-by-step approach ensures that the RFID-based parking system is optimized, convenient to use, and technologically robust to accommodate future advancements.

V. RESULTS AND DISCUSSION

The RFID-based parking system for vehicles was designed and installed in a test bed to evaluate its performance, functionality, and usability. The findings are explained below from the operational efficiency, accuracy, user interface, and overall system effectiveness perspectives.

A. System Accuracy and Reliability

MFRC-522 RFID reader was tested using several S50 RFID tags under different lighting and environmental conditions. The system was found to be:

Tag detection accuracy: ~98.7% in range 3–5 cm.
Response time: Under 2 seconds between scan and gate action.
Error rate: Very low, with infrequent failure due to incorrect orientation or positioning of tags.
Spurious readings and lost scans were minimized by optimizing the positioning of the antennas and ensuring constant power supply to the readers and the microcontroller.

B. Efficiency Improvement

In contrast to conventional parking systems:
Entry/exit time per vehicle reduced by ~60%.
Ticketing and logging manual labor was eliminated.
Recording of data was fully automated and timestamped for improved traceability and security.
The system could handle 100 cars per hour on average depending on hardware quality and network stability, and would be suitable for urban parking lots with medium traffic.

C. Real-Time Monitoring and Data Logging

The centralized database stored real-time information of every vehicle transaction, including:
1) Tag ID
2) Entry/exit times
3) Length of stay
4) Gate status (open/closed)
5) The admin panel showed:
6) Real occupancy rates
7) Trends in daily and weekly usage
8) Alerts for unauthorized tag usage

This enabled administrators to make decisions such as altering prices, re-allocating space, or applying peak hours based on data.

D. Security and Access Control

Each RFID tag was linked to a registered vehicle in a one-to-one fashion. Access control policies imposed by the system prevented:
1) Unauthorized use through unregistered tags
2) Several cloned-tag records (with additional anti-cloning measures in effect)
3) Manual bypass around barriers (other than override mode)
4) Security was also enhanced with the provision of deactivating lost or stolen tags through the admin panel.

E. User Experience and Feedback

Trial user feedback has been gathered from trial users (students and staff) who utilized the system.
Key findings:
1) Easy operation: The vast majority of consumers found the touchless entry solution convenient and curbed delays.
2) Trust and transparency: Real-time logging increased user trust in the system.
3) Recommendations for enhancement: Mobile app integration for space booking and license plate recognition were frequent requests.

F. Cost and Scalability Analysis

The prototype system was constructed at a relatively low cost with existing components:
RFID module (MFRC-522): INR 200–300
S50 card: INR 50 per unit
NodeMCU : INR 300–400
Servo motor: INR 200–300
Scalability problems: The design is modular and can be extended further by introducing additional RFID reader-microcontroller units at other entry/exit points. Cloud database integration would better accommodate multi-location deployment for larger institutions or cities.

G. Comparative Analysis

Feature	Traditional System	RFID-Based System (This Study)
Entry/Exit Time	6–10 seconds	1.5–2 seconds
Manual Labor	Required	Not Required
Real-Time Tracking	No	Yes
Data Logging	Paper-based/manual	Digital, timestamped
Security	Low	High (tag-based access)
Cost Over Time	High	Moderate

VI. CONCLUSION

The design and trial of the RFID-based automatic parking system fully justify the efficiency of its application in simplifying parking processes by means of automation, precision, and enhanced user satisfaction. Through the application of contactless RFID technology, the system drastically minimizes the need for human intervention, has low waiting times for entry and exit points, and guarantees secure and trustworthy vehicle access control.

Through rigorous testing, the system had high accuracy in tag detection, rapid gate response times, and reliable real-time data recording, all resulting in an optimized parking experience. Additionally, the centralized monitoring and data analysis capabilities open up new options for smart traffic management, space optimization, and administrative control.

The project demonstrates that with low-cost hardware components and simple integration processes, a cost-effective and scalable parking management system is possible. The system is also scalable by integrating mobile app, payment automation, and license plate recognition technologies to address the evolving needs of smart cities.

In total, the RFID-based parking system presents a realistic, scalable, and visionary solution to contemporary urban infrastructure issues.

VII. ACKNOWLEDGMENT

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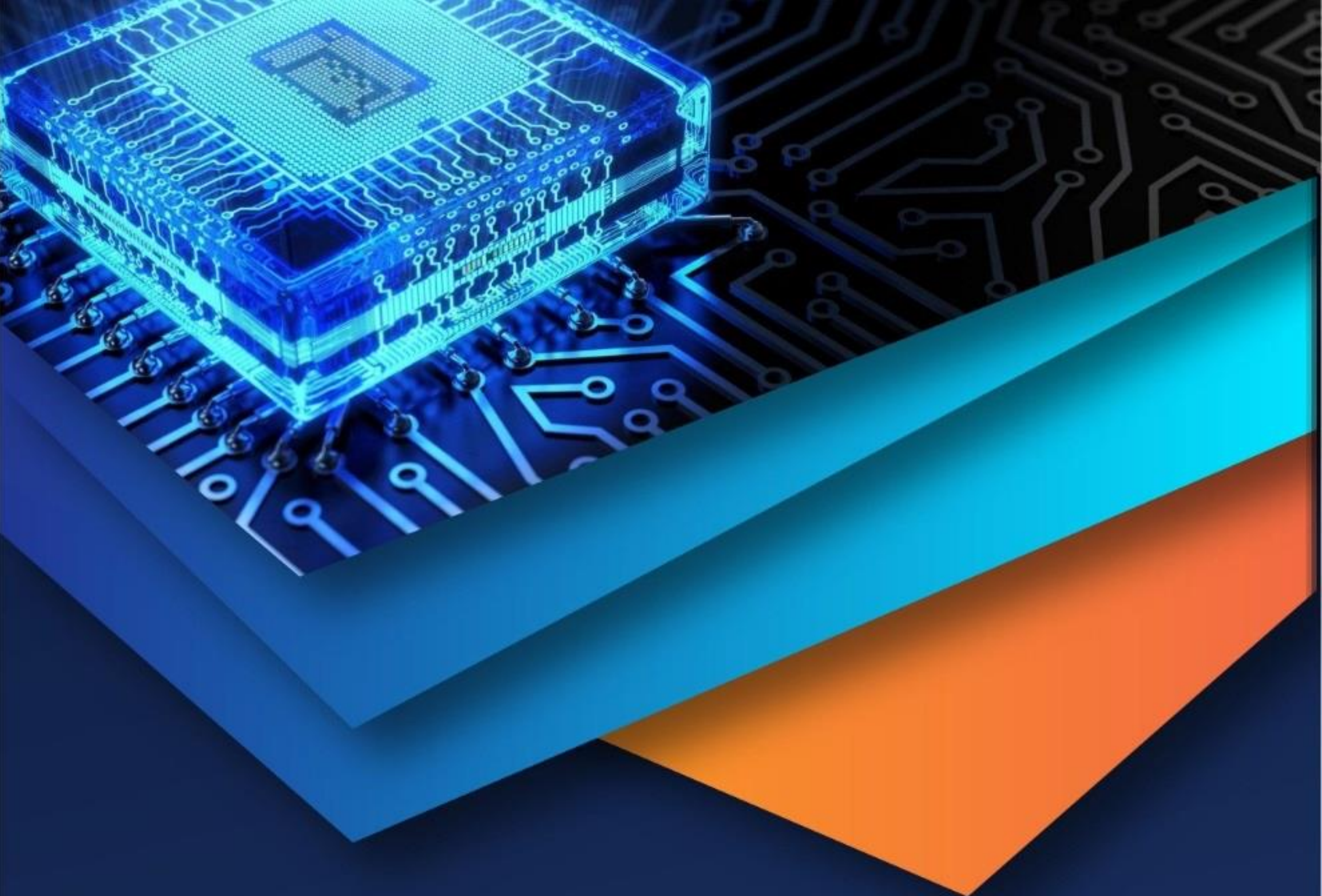

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