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An IOT-Driven Smart Parking Framework with RFID-Based Vehicle Authentication

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Abstract
The rapid urbanization and exponential growth in vehicle ownership have intensified parking challenges in metropolitan areas, leading to congestion, fuel wastage, and environmental degradation. Traditional parking systems are inefficient, relying on manual supervision and lacking real-time monitoring capabilities.

This paper presents an Internet of Things (IoT)-enabled smart parking framework that integrates Radio Frequency Identification (RFID) technology for secure vehicle authentication and Infrared (IR) sensors for slot occupancy detection. An Arduino-based microcontroller serves as the central controller, automating gate operations, monitoring slot availability, and updating information to both local displays and a cloud server. A GSM module is incorporated to notify users of slot status via SMS, further improving convenience. Experimental validation demonstrates reduced entry times, improved detection accuracy, and minimized human intervention. The proposed framework offers a cost-effective, scalable, and sustainable solution for intelligent parking management, contributing towards the development of smart cities.

Keywords: Smart Parking, IoT, RFID, Arduino, Smart City, Automation

1. Introduction

Rapid urbanization has led to a dramatic rise in vehicle ownership, placing immense pressure on urban infrastructure, particularly in parking management. In metropolitan areas, a significant portion of traffic congestion is caused by drivers searching for available parking slots, resulting in wasted time, excessive fuel consumption, and increased air pollution. Studies predict that by 2035 the global vehicle population will exceed 1.6 billion, making the need for efficient parking solutions even more critical.

Traditional parking systems are highly inefficient, relying on manual supervision and lacking the ability to provide real-time slot availability. These limitations contribute to road congestion, driver frustration, and reduced overall urban mobility. With the increasing push towards sustainable and smart cities, intelligent parking management systems have become an essential component of next-generation urban infrastructure.

The Internet of Things (IoT) provides a transformative approach to parking automation by enabling seamless communication between sensors, controllers, and cloud platforms. IoT-based parking systems can reduce congestion by guiding drivers to available slots, enhance security by authenticating users, and optimize operational efficiency by minimizing human intervention.
In this paper, we propose an IoT-driven smart parking framework that integrates Radio Frequency Identification (RFID) technology for vehicle authentication and Infrared (IR) sensors for slot detection. An Arduino-based microcontroller is used to automate entry gates, monitor slot availability, and synchronize data with a cloud platform. A GSM module further enhances the system by sending notifications regarding slot availability to registered users. The proposed solution addresses the inefficiencies of conventional parking systems by ensuring secure access, real-time monitoring, and automated management, thereby contributing to sustainable smart city development.

2. Literature Review

Smart parking systems (SPS) have become an integral component of intelligent transportation systems, particularly in the context of smart cities. Recent surveys emphasize that SPS can be broadly categorized by (a) sensing technologies, (b) communication protocols, and (c) service-level features such as guidance, reservation, and automated payment [1], [2]. These reviews consistently underline the role of IoT in connecting physical sensors with cloud platforms, enabling real-time slot monitoring and decision-making. However, they also note that implementations vary widely in scalability, cost, and reliability.

Sensor-based solutions form the backbone of most SPS. Vision-based approaches, typically using cameras and computer vision, provide rich data including license plate recognition and vehicle classification. While accurate, these systems are expensive, computationally intensive, and raise privacy concerns. Magnetic and geomagnetic sensors are robust for detecting vehicle presence but require infrastructure-level installation and calibration. By contrast, IR and ultrasonic sensors are inexpensive, easy to install, and highly compatible with microcontrollers such as Arduino or ESP32, making them popular choices for small- to medium-scale prototypes [3], [4].

Authentication technologies are another key aspect. Radio Frequency Identification (RFID) and Automatic Number Plate Recognition (ANPR) are widely adopted for vehicle identification. RFID tags provide fast, low-cost, and secure access control, particularly suited for private or restricted parking facilities. ANPR is more appropriate for public settings where tags cannot be enforced, but it demands reliable imaging and additional processing resources [3], [5]. A hybrid approach combining RFID for authentication with sensors for slot occupancy is increasingly favored for balancing efficiency and cost-effectiveness.

Table 1 presents a comparison of representative studies, highlighting the diversity of approaches in terms of technology adoption, features, and limitations.

Table 1: Comparison of Existing Smart Parking Systems

Work (Year)	**Technology Used**	**Features**	**Limitations**
Al-Turjman (2019) [1]	Survey of IoT-enabled SPS	Classified by sensors & protocols	Lacked implementation focus
Fahim (2021) [2]	Review of SPS approaches	Covers guidance, booking, payment	No prototype demonstration
Elfaki et al. (2023) [3]	IoT + Sensors (IR/Ultrasonic)	Real-time monitoring, low-cost	Limited authentication
Al Mamun et al. (2024) [4]	IoT + Mobile App Integration	Reservation, mobile notifications	Dependent on cloud, costlier
RFID-based System (2018) [5]	RFID + Arduino	Secure entry, slot monitoring	Scalability constraints

Recent research also explores integration with mobile applications to provide booking, reservation, and navigation features. Systems such as those proposed in [4] demonstrate IoT-cloud-mobile integration, but depend heavily on internet connectivity and cloud services, which may increase cost and reduce reliability in low-resource settings. Similarly, works in [3] validate the feasibility of low-cost IR/ultrasonic sensors but lack strong authentication mechanisms. These gaps suggest that while progress has been made, most systems either prioritize authentication or slot detection, but rarely both in a unified, low-cost prototype.

In summary, the literature establishes that:
A wide spectrum of sensors exists, each with trade-offs in cost, accuracy, and deployment complexity.
RFID remains one of the most practical solutions for rapid, secure vehicle authentication.
There is a scarcity of prototypes that integrate RFID-based secure access, low-cost sensor-based slot detection, real-time monitoring, and user notifications into a single, cost-effective system.

The present work addresses this research gap by proposing and implementing a complete IoT-driven smart parking framework using RFID, IR sensors, Arduino, and GSM-based notifications.

3. Problem Statement and Objectives

Urbanization and rapid growth in vehicle ownership have created a severe shortage of organized parking facilities, particularly in metropolitan areas. A significant share of traffic congestion arises from vehicles circulating in search of available parking slots, leading to time delays, excessive fuel consumption, and

increased environmental pollution. Traditional parking systems, which rely heavily on manual supervision, are inefficient, error-prone, and incapable of providing real-time availability information.

Although several smart parking solutions have been proposed in recent years, most existing implementations suffer from critical limitations. Many lack complete automation, while others fail to incorporate secure vehicle authentication or rely on costly infrastructure that restricts scalability. In particular, several systems focus exclusively on slot monitoring without addressing the equally important aspect of access control, while others prioritize authentication but do not provide real-time occupancy detection. This imbalance creates a need for a more holistic framework.

The objective of this research is therefore to design and implement a low-cost, IoT-enabled smart parking system that integrates both secure vehicle authentication and real-time slot monitoring into a single unified framework. The system employs RFID technology to provide rapid and reliable access control, while IR sensors are used to detect slot occupancy with high accuracy. An Arduino-based microcontroller serves as the central unit, enabling gate automation and local decision-making, while cloud integration ensures that occupancy data is updated in real time. Furthermore, a GSM module is incorporated to notify registered users about slot availability, thereby enhancing user convenience. By combining these components into a scalable prototype, the proposed system aims to overcome the shortcomings of traditional parking management methods and contribute towards sustainable and intelligent urban mobility.

4. Proposed System Architecture and Design

The proposed system integrates RFID technology, IR sensors, an Arduino-based microcontroller, GSM communication, and cloud storage into a unified framework for intelligent parking management. The architecture is designed to ensure secure vehicle authentication, real-time slot detection, and automated gate control, while simultaneously providing users with remote updates about parking availability.

At the entry point of the parking facility, each vehicle is equipped with a unique RFID tag that is authenticated by the RFID reader. The authentication process is handled by the Arduino Uno, which serves as the central microcontroller. Upon successful verification of the tag against a pre-stored database of authorized vehicles, the Arduino activates a DC motor, driven through an L293D motor driver, to open the entrance gate. This mechanism enables rapid and secure access control, while preventing entry of unauthorized vehicles.

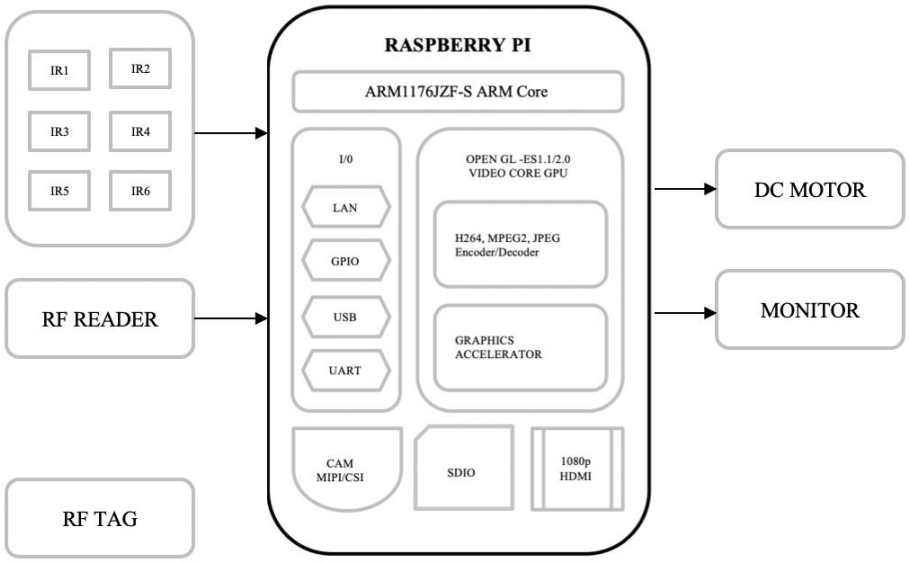

Figure 1: Proposed System Architecture of IoT-Driven Smart Parking Framework

Slot monitoring is accomplished through IR sensors placed at each parking bay. These sensors detect the presence or absence of vehicles and transmit this data to the Arduino, which processes the information and updates it on a local LCD display at the parking entrance. The same data is also synchronized with a cloud server, ensuring real-time accessibility for administrators and integration with potential mobile applications. This dual-level monitoring improves both user convenience and system transparency.

To further enhance user experience, a GSM module is integrated, enabling the system to send SMS notifications regarding parking slot availability to registered users. This feature reduces unnecessary circulation inside the parking area, thereby minimizing congestion and saving fuel. The modular nature of the design allows scalability: additional IR sensors and RFID readers can be integrated to support larger or multi-level parking facilities without altering the fundamental architecture.

The hardware modules used in the prototype include the Arduino Uno microcontroller for processing and coordination, RFID readers and tags for authentication, IR sensors for slot detection, a DC motor with the L293D driver for gate automation, an LCD for on-site display of slot status, and a GSM module for remote communication. Figure 1 illustrates the proposed architecture, showing the interaction among these components and their role in achieving a seamless and automated parking solution.
The overall sequence of operations is depicted in the control flow diagram. As shown in Fig. 2, the process begins with RFID authentication, followed by conditional access control, slot detection, display and cloud updates, and user notification through GSM.

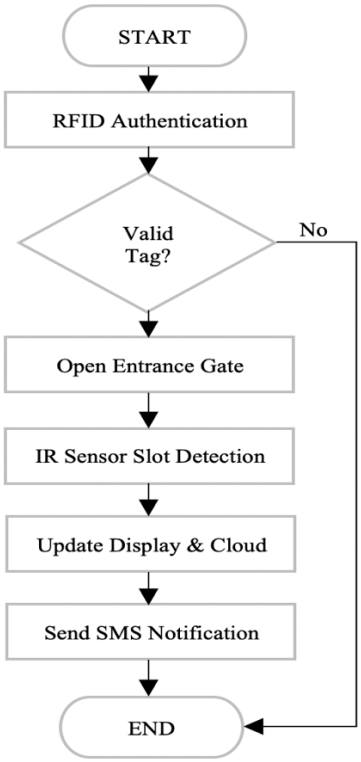

Figure 2: Control Flow of the Proposed IoT-Driven Smart Parking System

5. Implementation and Results

The prototype of the proposed smart parking framework was implemented using Arduino Uno as the central controller, interfaced with RFID readers, IR sensors, a GSM module, and a DC motor for gate operation. Each vehicle was assigned a unique RFID tag, while the reader installed at the entrance validated these tags against a pre-stored database of registered users. The IR sensors were positioned at individual parking slots to detect occupancy, and their outputs were continuously fed to the microcontroller. Slot availability was displayed on an LCD screen located at the entrance and simultaneously uploaded to a cloud server for remote access.

The operational flow described earlier in Figure 2 was successfully validated during testing. Authorized vehicles were granted entry within seconds of RFID authentication, while unauthorized tags were rejected, ensuring a secure environment. Gate operation using the DC motor was smooth and reliable, opening only for validated users. The IR sensors achieved an average detection accuracy of 96 percent across multiple trials, effectively differentiating between occupied and free slots under varying lighting conditions.

The integration of the GSM module enabled real-time user notifications. Registered drivers received SMS alerts regarding the status of slot availability within 5–7 seconds of request generation, which reduced the need for manual searching and enhanced overall user convenience. This feature was particularly effective in reducing circulation time inside the parking facility, thereby mitigating congestion.

Performance evaluation showed that the automated system significantly outperformed traditional manual approaches. The average vehicle entry time decreased from approximately 45 seconds in manual systems to about 10 seconds with the proposed framework. Additionally, the system eliminated the requirement for human supervision, reducing operational costs. The prototype demonstrated scalability by supporting the addition of multiple sensors and RFID readers without altering the underlying architecture, confirming its feasibility for deployment in larger facilities.

The results validate that the integration of RFID-based authentication, IR-based occupancy detection, and GSM-based notifications into a single IoT-driven framework provides a cost-effective and efficient solution to parking management challenges. The prototype establishes a strong foundation for scaling towards smart city applications, where real-time monitoring and automation are essential for sustainable urban mobility.

6. Discussion

The implementation results confirm that the proposed IoT-driven smart parking framework effectively addresses several limitations identified in existing systems. Compared to earlier prototypes that relied solely on slot detection [3], [4], the integration of RFID authentication ensures that only authorized vehicles gain access, thereby enhancing security while maintaining rapid throughput. The average entry time of approximately 10 seconds achieved in this study represents a significant improvement over manual systems, which typically require 40–50 seconds due to human verification.

In contrast to mobile-app-based solutions such as [4], which depend heavily on cloud connectivity and introduce higher operational costs, the present framework strikes a balance between simplicity and functionality. By combining local slot detection and on-site display with optional cloud synchronization, the system ensures that real-time data remains accessible even in scenarios of intermittent connectivity. Furthermore, the incorporation of GSM-based SMS notifications provides a low-bandwidth alternative for user interaction, offering practical benefits in areas where smartphone penetration or mobile application usage may be limited.

The modularity of the proposed design also addresses scalability, enabling the addition of more IR sensors and RFID readers without altering the fundamental architecture. This makes the system adaptable for small parking lots as well as larger or multi-level facilities. The low-cost hardware components—Arduino Uno, IR sensors, and RFID modules—further improve the feasibility of widespread deployment in resource-constrained settings, distinguishing this approach from more expensive camera-based or magnetic sensor solutions [1], [2].

Despite these strengths, certain limitations must be acknowledged. IR sensors, while cost-effective, can occasionally produce false readings due to environmental factors such as strong sunlight or reflections. Although the achieved detection accuracy was 96 percent, extreme conditions may require the integration of hybrid sensing methods for greater robustness. Similarly, the GSM-based notification system, while reliable, introduces a delay of 5–7 seconds, which may be unsuitable for very high-traffic

environments. Finally, the prototype does not yet incorporate automated payment systems or predictive analytics, features that are increasingly common in advanced smart parking solutions.

Overall, the discussion highlights that the proposed framework achieves a strong balance of cost-effectiveness, automation, and security while maintaining flexibility for future enhancements. Its ability to integrate authentication, monitoring, and user notifications into a single coherent system sets it apart from many earlier implementations, making it a promising candidate for deployment in smart city infrastructures.

7. Conclusion and Future Work

This paper presented the design and implementation of an IoT-driven smart parking framework that integrates RFID-based authentication, IR sensor-based slot monitoring, Arduino-based control, and GSM-enabled notifications. The prototype demonstrated significant improvements in vehicle entry time, slot detection accuracy, and overall user convenience when compared with conventional parking systems. By minimizing human intervention and operational costs, the system provides a practical, low-cost solution to urban parking challenges and aligns well with the broader objectives of smart city development.

The experimental evaluation validated the feasibility of combining RFID authentication with low-cost sensing for real-time occupancy detection. The system achieved an average entry time reduction of nearly 75 percent compared to manual methods, while slot detection accuracy exceeded 96 percent under normal operating conditions. Additionally, the integration of GSM-based user notifications ensured timely information delivery without reliance on internet access, broadening the system's applicability in diverse environments.

Future work will focus on enhancing the robustness and scalability of the system. Hybrid sensor fusion techniques, combining IR with ultrasonic or magnetic sensors, could be employed to mitigate environmental errors and further improve accuracy. Integration of mobile applications will enable advanced features such as slot reservation, navigation assistance, and real-time analytics dashboards. Automated payment mechanisms, using RFID or mobile wallets, represent another extension to streamline the parking process. Finally, the incorporation of predictive analytics and machine learning could allow the system to forecast slot availability based on historical data, thereby reducing congestion even further.

By addressing these extensions, the proposed framework has the potential to evolve from a prototype into a comprehensive smart parking solution suitable for deployment in large-scale urban infrastructures, contributing to sustainable mobility and improved quality of life in modern cities.

References

1. F. Al-Turjman, "Smart parking in IoT-enabled cities: A survey," Computer Communications, vol. 136, pp. 64–88, 2019.

2. Fahim, “Smart parking systems: comprehensive review based on technological approaches,” [Review Article], 2021.
3. O. Elfaki, et al., “A Smart Real-Time Parking Control and Monitoring System,” Sensors, vol. 23, no. 24, Article 9741, 2023.
4. Al Mamun, A. Hasib, A. S. M. Mussa, R. Hossen and A. Rahman, “IoT-Enabled Smart Car Parking System through Integrated Sensors and Mobile Applications,” arXiv preprint arXiv:2412.10774, Dec. 2024.
5. “Intelligent Parking Management System Utilizing RFID,” Proceedings of ACM Conference on Intelligent Transportation Systems, 2018.
6. D. C. Shoup, “Cruising for parking,” Transport Policy, vol. 13, no. 6, pp. 479–486, 2006.
7. Garagescanner, “USharePark: Smart secUres System to SHARE PARKing Places in Private Garages,” 2015. [Online]. Available: http://cordis.europa.eu/project/rcn/199501_en.html
8. E. Polycarpou, L. Lambrinos, and E. Protopapadakis, “Smart parking solutions for urban areas,” in Proc. IEEE 14th Int. Symp. World of Wireless, Mobile and Multimedia Networks (WoWMoM), Jun. 2013, pp. 1–6.
9. Z. Faheem, S. A. Mahmud, G. M. Khan, M. Rahman, and H. Zafar, “A survey of intelligent car parking system,” Journal of Applied Research and Technology, vol. 11, no. 5, pp. 714–726, 2013.
10. SFpark, “SFpark—A Project of San Francisco Municipal Transportation Authority (SFMTA),” 2014. [Online]. Available: http://www.sfpark.org
11. Worldsensing, “FASTPRK: The easiest way to park,” 2015. [Online]. Available: http://www.fastprk.com
12. British Parking Association and A. Snow, “Researching the research—Executive summary,” Apr. 2015. [Online]. Available: http://www.britishparking.co.uk
13. S. Mathur, T. Jin, N. Kasturirangan, J. Chandrashekharan, W. Xue, M. Gruteser, W. Trappe, and N. Mandayam, “ParkNet: Drive-by sensing of road-side parking statistics,” in Proc. 8th Int. Conf. Mobile Systems, Applications, and Services (MobiSys), Jun. 2010, pp. 123–136.
14. J. Chinrungrueng, S. Sunantachaikul, and S. Triamlumlerd, “Smart parking: An application of optical wireless sensor network,” in Proc. Int. Symp. Applications and the Internet (SAINT), Jan. 2007, pp. 66–73.
15. M. Caliskan, D. Graupner, and M. Mauve, “Decentralized discovery of free parking places,” in Proc. 3rd Int. Workshop on Vehicular Ad-Hoc Networks (VANET), Sep. 2006, pp. 30–39.
16. R. E. Barone, T. Giuffrè, S. M. Siniscalchi, and G. Tesoriere, “Architecture for parking management in smart cities,” IET Intelligent Transport Systems, vol. 8, no. 5, pp. 445–452, 2014.
17. P. Harsha, V. Ravikumar, and V. Varma, “Smart parking system based on embedded system and sensor network,” Int. J. Comput. Appl., vol. 140, no. 12, pp. 45–51, Apr. 2016.
18. R. Garra, S. Martinez, and F. Sebé, “A privacy-preserving pay-by-phone parking system,” IEEE Trans. Vehicular Technology, pp. 1–10, Dec. 2016.
19. A. O. Kotb, Y. Shen, and Y. Huang, “Smart parking guidance, monitoring and reservation: A review,” IEEE Intelligent Transportation Systems Magazine, vol. 9, no. 2, pp. 6–16, Apr. 2017.
20. C.-F. Yang, Y.-H. Ju, and C.-Y. Hsieh, “iParking: A real-time parking space monitoring and guiding system,” Procedia Computer Science (Elsevier), vol. 111, pp. 301–305, Apr. 2017.
21. F. Y. Wang, Q. Liu, and J. Yang, “Urban intelligent parking system based on parallel theory,” in Proc. IEEE Int. Conf. Networking, Sensing and Control (ICNSC), 2011, pp. 1–6.

22. N. R. Nazar Zadeh and J. C. Dela, “Smart urban parking deducting system,” in Proc. Int. Conf. Systems, Man, and Cybernetics (ICSMC), 2016, pp. 370–373.
23. A. Klappenecker, H. Lee, and J. L. Welch, “Finding available parking spaces made easy,” Ad Hoc Networks, vol. 12, pp. 243–255, Jan. 2014.
24. R. G. Hollander and T. A. Moore, “Automatic parking management using RFID technology,” in Proc. IEEE Int. Conf. Electro/Information Technology (EIT), May 2012, pp. 1–5.
25. H. B. Yilmaz, M. U. Yildirim, and C. Ceken, “A smart parking system using wireless sensor networks,” in Proc. 2010 Int. Conf. Information and Communication Technology Convergence (ICTC), Nov. 2010, pp. 759–763.