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Design and Implementation of an RFID-Based Smart Parking System for Automated Vehicle Access Control

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ABSTRACT: The increasing volume of vehicles in urban and institutional settings presents significant challenges in managing parking facilities efficiently and securely. This study proposes designing and implementing a Smart Car Parking System utilizing Radio Frequency Identification (RFID) technology to automate vehicle access and monitoring within parking premises. The project aims to minimize human intervention by equipping each authorized user with an RFID tag embedded with pre-programmed identification details. A card reader, interfaced with an Arduino Uno and Wi-Fi module, captures the RFID data and communicates with a centralized MySQL database that authenticates user credentials in real time. Once validated, a servo motor triggers the barrier gate, granting or denying access accordingly. The system's development followed the Waterfall methodology, encompassing requirement analysis, system design, coding, testing, implementation, and deployment phases. A key feature includes real-time logging of time-in and time-out data, which is viewable on a server-side graphical interface. This integration supports enhanced monitoring, security, and data tracking without manual supervision. Initial testing revealed system efficiency, with some bugs resolved during the debugging stage. The final prototype functioned effectively in live simulation environments. This intelligent system demonstrates potential for deployment in schools, malls, companies, and other gated institutions seeking efficient, secure, and user-friendly parking management.

KEYWORDS: RFID Technology, Arduino Integration, Database Authentication. Automated Access Control, Smart Parking System

I. INTRODUCTION

The increasing volume of vehicular traffic in urban centers and institutional settings has necessitated the adoption of smarter, automated parking management systems. Traditional manual parking approaches are not only time-consuming but also prone to errors, inefficiencies, and security vulnerabilities. In response to these challenges, this study proposes a Smart Car Parking System leveraging Radio Frequency Identification (RFID) technology, designed to regulate the entry and exit of vehicles within a parking facility with minimal human intervention.
At the core of this system is the integration of RFID technology, wherein each registered user is issued an RFID tag or transponder pre-programmed with their personal credentials. These tags are uniquely associated with the user's identity, allowing seamless authentication during parking transactions. The other end of the system consists of an RFID reader (transceiver), strategically installed at the parking area entrance and exit gates. When a user places their tag near the reader, it transmits the tag's data to a centralized hosting computer system. This system then verifies the data against a secured MySQL database to determine authenticity and, upon successful verification, grants or denies access accordingly (Teleron, 2022a; Anusha, 2016).

The RFID-based system is built not only to streamline parking access but also to enhance security by recording every transaction. It automatically logs the time-in and time-out events, storing the details in the database for future reference. As noted by Prince et al. (2018), systems that utilize RFID for vehicle tracking exhibit high identification accuracy, significantly reducing manual monitoring requirements while improving overall user convenience. Moreover, this technology can be particularly beneficial in gated communities, academic institutions, malls, and corporate facilities, where rapid and accurate access control is essential.

Manual parking systems continue to face operational inefficiencies and congestion issues, particularly during peak hours. These inefficiencies are exacerbated by the need for human supervision, which introduces risks of inconsistency, unauthorized access, and administrative overhead. In contrast, RFID-based smart parking systems provide real-time tracking, faster processing of vehicle entry and exit, and reduced labor costs, as emphasized by Pala (2007) and further validated by Teleron (2022b) in the context of distributed RFID applications.

The development lifecycle of the proposed system follows a structured and methodical approach as illustrated in Figure 1. This Figure outlines the sequential phases undertaken in the system's development. The first stage is the Board of Concepts, where researchers identify the system requirements and objectives. Next is the Programming Language Identification phase, where technologies such as C, C++, PHP, HTML, JavaScript, Java, SQL, and CSS are selected for their respective backend and frontend functions. This is followed by Hardware Configuration, in which the appropriate microcontrollers, RFID readers, Wi-Fi adapters, and servo motors are specified.

Subsequently, the Database Integration phase focuses on establishing a MySQL database where all RFID tag data and user credentials are securely stored. Afterward, the Graphical User Interface (GUI) Design stage enables administrators to interact with the system through a user-friendly dashboard for encoding user details. The next phases —Testing and Implementation—involve trial runs of the system, debugging, and adjustments based on performance metrics. Finally, in the Deployment stage, the fully functioning system is launched in the actual environment, ready for end-user interaction and real-world application.

By implementing this RFID-based smart parking framework, the system not only automates vehicle access but also contributes to digital transformation in institutional operations. It addresses the pressing need for efficient traffic flow, security assurance, and user satisfaction in parking management, providing a scalable and reliable solution to the growing problem of parking congestion.

Conceptual Framework

The figure illustrates the systematic process undertaken in the development of the Smart Car Parking System, from conceptual planning to full deployment, highlighting each critical stage from hardware selection and programming to database integration and live implementation.

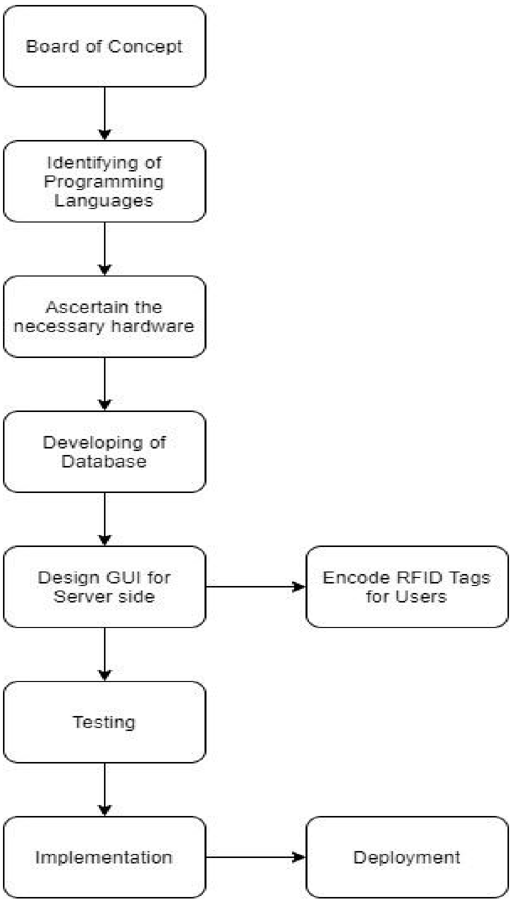

Fig. 1 Conceptual Framework

REVIEW OF THE RELATED LITERATURE

The proliferation of vehicular traffic in modern urban centers has necessitated the development of automated systems for efficient parking management. Traditional manual systems often suffer from inefficiencies such as time delays, human error, and increased security risks. To address these challenges, various technologies—including RFID, Internet of Things (IoT), and embedded systems—have been explored in the context of smart parking.

1. RFID Technology in Parking Management

Radio Frequency Identification (RFID) has emerged as a core component of intelligent transportation systems due to its capability for non-contact identification and rapid data exchange. According to Prince et al. (2018), RFID-based parking systems enable efficient vehicle tracking and secure access control, reducing the need for human intervention. These systems typically employ RFID tags affixed to vehicles and readers positioned at entry/exit points to authenticate and log access events in real-time.

Pala (2007) emphasized that RFID applications in smart parking offer high scalability and reliability, particularly in congested areas where speed and accuracy are crucial. The integration of RFID with servo motors and microcontrollers like Arduino allows for seamless automation of gates and barriers, enhancing operational efficiency.

2. Embedded Systems and Microcontroller Integration

Microcontrollers such as the Arduino Uno have been widely adopted for prototyping and implementing automated parking solutions. Kaliappan (2018) noted that embedded systems play a pivotal role in managing real-time responses and executing control commands such as gate actuation. These systems are often programmed using languages like C and C++, and they interface with peripherals including sensors, motors, and RFID modules.

Teleron (2022b) demonstrated the effectiveness of using multiple microcontrollers in distributed environments, reinforcing the feasibility of using compact systems for large-scale applications like campus parking automation.

3. Database-Driven Access Control

Secure authentication is central to the effectiveness of automated parking systems. MySQL and other relational databases are frequently used to store user credentials and RFID tag information. Khan (2019) suggested that database integration not only enhances the security of access control but also facilitates detailed record-keeping for monitoring and auditing purposes.

The study by Smith (2021) further supports this approach, highlighting the importance of real-time synchronization between the RFID reader, microcontroller, and the centralized server. Systems that implement this architecture benefit from reduced data redundancy and improved accuracy in log records.

4. Wireless Communication and IoT Connectivity

The evolution of IoT has allowed smart parking systems to utilize wireless modules such as the ESP8266 for seamless data transmission between edge devices and cloud-based platforms. Zhang and Lee (2019) observed that Wi-Fi-enabled parking systems enable remote monitoring, immediate data updates, and administrative control via web interfaces, making them highly suitable for institutions and commercial areas.

Li and Zhang (2018) also highlighted the advantages of cloud-based RFID systems in dynamic environments, citing improved scalability and reduced wiring complexity as key benefits.

5. User Experience and System Reliability

Tan and Wong (2020) studied user satisfaction in automated systems and found that real-time responsiveness, reliability, and transparency of the access control process significantly affect user perception. Similarly, Patel (2021) argued that user-friendly interfaces and minimal delays in gate operation are crucial for system adoption in real-world applications.

In the present study, the Smart Parking System incorporates a user interface that displays access logs, timestamps, and departmental affiliations, thereby promoting transparency and traceability.

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Objectives of the Study

This study aims to develop and implement a Smart Car Parking System that operates with minimal human intervention while ensuring enhanced security and efficient user monitoring. By utilizing Radio Frequency Identification (RFID) technology, the system is designed to automate vehicle access, reduce manual labor, and streamline entry and exit processes. Furthermore, the system promotes data integrity by encoding user information into uniquely assigned RFID tags, enabling administrators to effectively monitor, authenticate, and log vehicle activity within the parking facility.

Specifically, the objectives of the study are as follows:

1. **To integrate Radio Frequency Identification (RFID) technology** as the core mechanism for enabling automated access control and vehicle identification.
2. **To establish a secure authentication process** that verifies user identity through a centralized database, ensuring that only registered individuals can access the parking premises.
3. **To implement a reliable validation protocol** that confirms user authorization upon scanning the RFID tag, allowing seamless and accurate gate operation.

II. METHODOLOGY

This study adopts the Waterfall Model methodology, a well-established linear and sequential approach in system development. In this model, each phase must be fully completed before proceeding to the next, ensuring a systematic flow of activities. Notably, the Waterfall Model does not allow overlapping or iterative progression between phases, thereby promoting clarity, discipline, and thorough documentation at each stage. This methodology is particularly suited for projects with clearly defined requirements and objectives, such as the RFID-based Smart Car Parking System developed in this study.

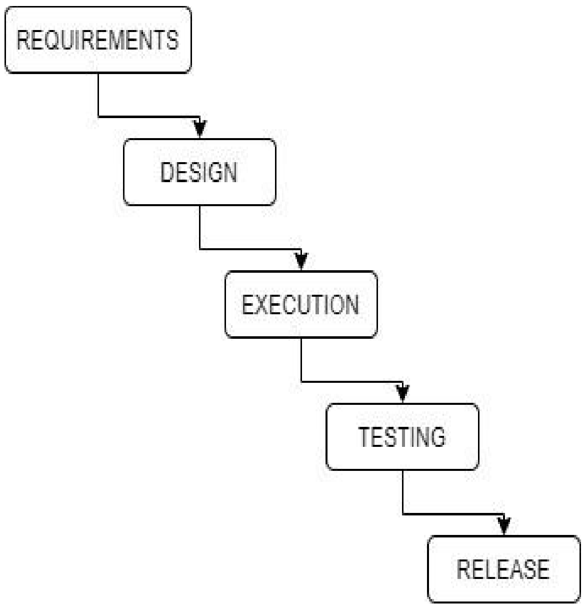

Fig 2. Schema of the study

A. Requirement Phase

The initial phase of the system development process focuses on requirements analysis, wherein the researchers identify the necessary data and parameters essential to the successful design and implementation of the Smart Car Parking System. This includes a thorough assessment of the operational environment, particularly establishments equipped with designated parking areas such as academic institutions, business complexes, and gated communities. Additional data, such as the average number of vehicles entering and exiting the facility daily, user access frequency, and security needs, were also considered. These inputs are crucial in defining the system's functional scope and ensuring that the proposed solution addresses the real-world demands of automated parking management.

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B. Design Phase

The design phase centers on the architectural development of the RFID-based Smart Car Parking System. At this stage, the system is conceptualized into two primary interaction components. On the user side, drivers are equipped with RFID tags, which they present to strategically positioned RFID card readers at entry and exit points. These readers serve as the system's access gateways. When a tag is detected, the reader communicates with the central server to validate the encoded user information. If authenticated, the system triggers the mechanical gate to allow vehicle passage. This design ensures seamless automation, accurate identification, and minimal manual intervention, forming the foundation of the smart parking workflow.

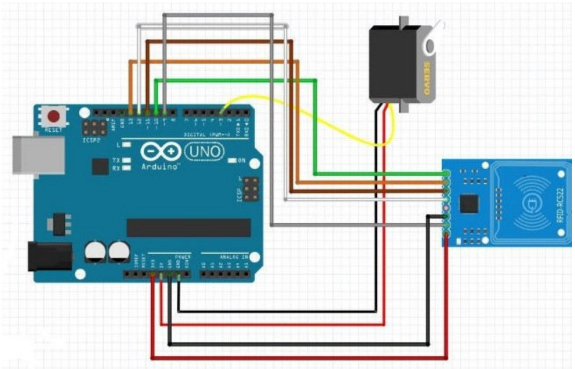

Fig 3. Arduino UNO

As illustrated in **Figure 3**, the system integrates an **Arduino UNO** microcontroller with an **RFID reader** and a **servo motor**, forming a critical part of the hardware infrastructure. When a user presents their RFID tag to the reader, the embedded software program processes the input and activates the corresponding components. Specifically, upon successful tag detection, the Arduino triggers the servo motor to operate the gate mechanism, raising or lowering the barrier to grant or deny access. This configuration ensures real-time responsiveness and reliable control, serving as a foundational mechanism for the automated access system.

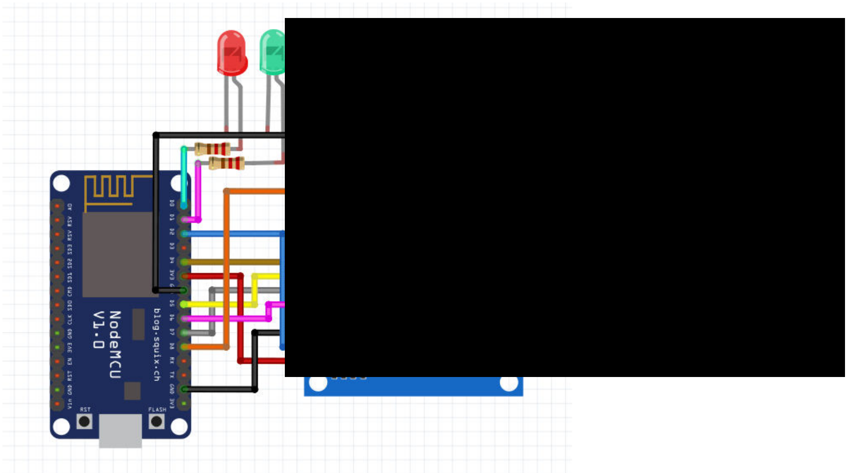

Fig 4. A ESP8266 Wi-Fi module adapter

As depicted in **Figure 4**, a **Wi-Fi adapter** (such as the ESP8266 module) is interfaced with the **RFID reader** to enable wireless transmission of data to the central server. When the RFID reader scans a tag, the captured data is transmitted through the Wi-Fi module to the server, where it is cross-verified against the records stored in the **MySQL database**. Based on the result of this authentication process, the system determines whether access should be granted or denied. This wireless communication setup enhances the system's scalability and eliminates the need for extensive cabling, thus making the solution more efficient and adaptable for various infrastructure layouts.

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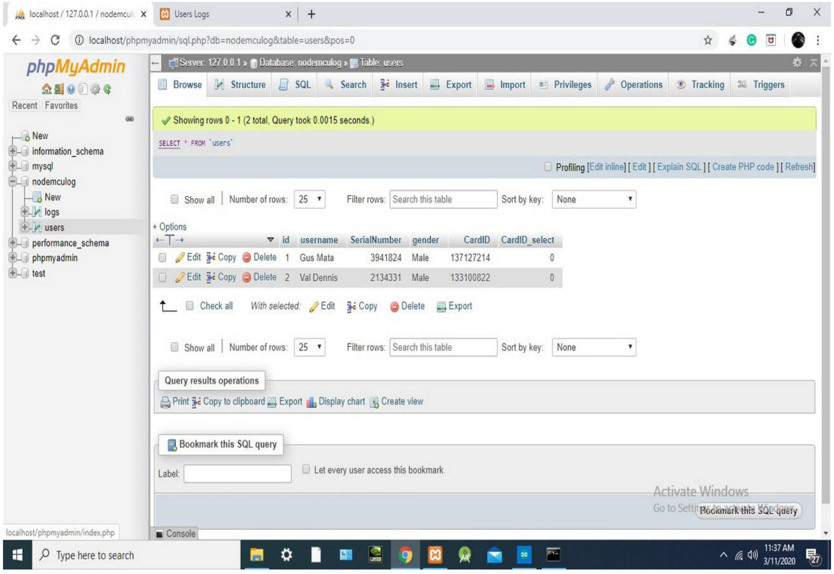

Fig 5. MySQL Database

As shown in **Figure 5**, the **MySQL database** is structured to store essential user information required for authentication. Each RFID tag assigned to a user is linked to four specific data fields: **name**, **gender**, **serial number**, and **card identification number**. These data elements serve as the basis for validating the user's identity during system interactions. When an RFID tag is scanned, the system queries the database to match the input data with existing records, ensuring that only registered users are granted access. This structured approach to data management enhances the security, accuracy, and reliability of the smart parking system.

A. Execution

The researchers programmed each RFID tag with a unique card identification number alongside the basic details of the user. The reader receives a signal from the nearby tag via radio frequency and an algorithm is then initiated to differentiate the card number from the RFID tag and the database. Upon confirmation of the user's tag, a timestamp is displayed on the server's monitor. The programming languages implemented in the dissemination of data from the tags and readers are Java, JavaScript, C, and C++. Whereas, the programming languages that the researchers used in publishing the data into the server are PHP (Personal Home Page), HTML (HyperText Markup Language), CSS (Cascading Style Sheets), and SQL (Structured Query Language). These languages are utilized in both the front end and back end of the system.

B. Testing Phase

Following the integration of all system components, a comprehensive testing phase was conducted to ensure the functionality and stability of the Smart Car Parking System. Each module—including the RFID reader, servo motor, Wi-Fi module, and server-side database—was evaluated individually and as part of the complete system. During this phase, the researchers identified and documented several operational bugs:

1. **Time-in Function Limitation**: The system allowed the time-in function to be recorded only once per user. However, the time-out function could be triggered multiple times, leading to the overwriting of previously logged exit times.
2. **Delayed Gate Response**: A noticeable delay occurred between the successful recognition of the RFID tag and the actual actuation of the gate mechanism.

These issues were addressed through software debugging and code refinement to improve system responsiveness and ensure accurate time-logging behavior.

Alongside the testing phase, the researcher developed a comprehensive set of algorithms and logical sequences that govern the operation of the system. These procedural steps were structured into a detailed process flow to ensure clarity in the interaction between hardware components and the software logic. As a result, a system flowchart was created to visually represent the sequential activities involved in vehicle detection, RFID scanning, data transmission, authentication, and gate control. This flowchart, presented in Figure 6, serves as a blueprint for understanding the internal operations of the Smart Car Parking System, highlighting the decision-making points and the automated responses triggered throughout the process.

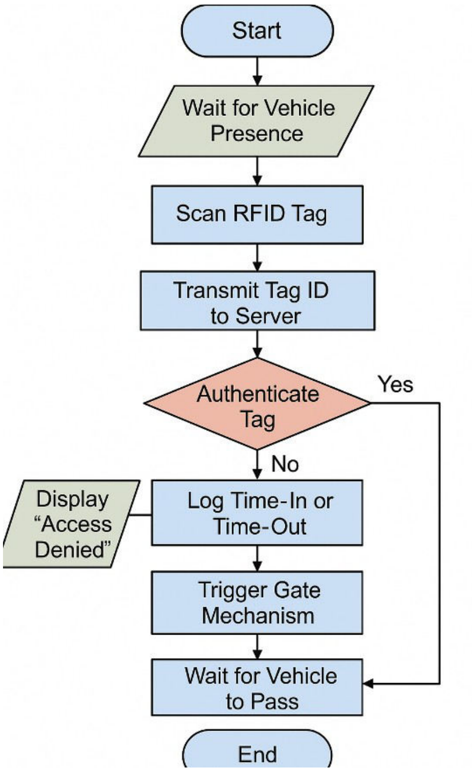

Fig 6. System Flowchart

Systems Algorithms

The operational logic of the Smart Car Parking System is governed by a clearly defined algorithm that ensures systematic vehicle access control through RFID verification. The process begins with system initialization, wherein the RFID reader, Arduino microcontroller, ESP8266 Wi-Fi module, and MySQL database server are powered up and connected. All variables are initialized, and the gate is set to its default position—closed. Once operational, the system waits for the presence of a vehicle, which may be detected using an optional proximity sensor or inferred when a user presents an RFID tag. Upon detection, the RFID reader captures the unique tag ID and transmits it to the server via the Wi-Fi module. The server then checks this tag ID against its stored records in the MySQL database. If the tag ID is recognized and valid, the process continues; otherwise, the system displays an "Access Denied" message and returns to the initial waiting state. For valid entries, the system logs the event as either a time-in or time-out based on the user's most recent activity and records the corresponding timestamp and date. Following successful authentication, the Arduino triggers the servo motor to lift the gate while displaying an "Access Granted" message. After a brief delay, typically around five seconds to allow vehicle passage, the gate closes automatically. The system then resets its input buffer, making it ready for the next vehicle, and continues this loop continuously for real-time operation.

C. Release Phase

Upon successful testing and resolution of identified issues, the system transitioned to the **release phase**. This involved finalizing the application for deployment in real-world environments such as school campuses, business establishments, or gated residential communities. After passing all functional and non-functional requirements, the Smart Car Parking System was deemed ready for production use. Administrators were trained on system operations, and documentation was prepared to support ongoing maintenance. Should any complications arise post-deployment, the system is equipped with administrative controls that allow immediate troubleshooting and real-time configuration updates.

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III. RESULTS AND DISCUSSIONS

After conducting multiple rounds of testing and extensive troubleshooting, the Smart Car Parking System was successfully developed and transitioned into its final functional state. The integrated system now operates reliably, fulfilling its intended purpose with minimal human intervention. Each component—from RFID-based access authentication to automated gate control and data logging—functions cohesively, enabling efficient and secure vehicle management within the parking facility. The results confirm that the implemented architecture effectively supports real-time user identification, seamless access control, and accurate recording of entry and exit activities. These outcomes validate the system's design objectives and demonstrate its applicability in real-world environments.

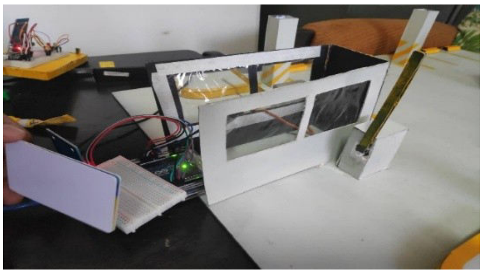

Fig 7. Gate activated after RFID tag is read

As illustrated in **Figure 7**, the entrance to the parking area is equipped with a **barrier gate system** that operates through RFID-based access control. When a user presents their RFID tag to the card reader positioned near the gate, the reader transmits the data to the server for authentication. Upon successful verification of the tag's credentials, the system signals the servo motor to lift the barrier, thereby granting the vehicle entry into the parking vicinity. This mechanism ensures a seamless and secure access process. The same procedure is applied at the exit gate, enabling controlled and automated departure while maintaining an accurate log of all parking transactions.

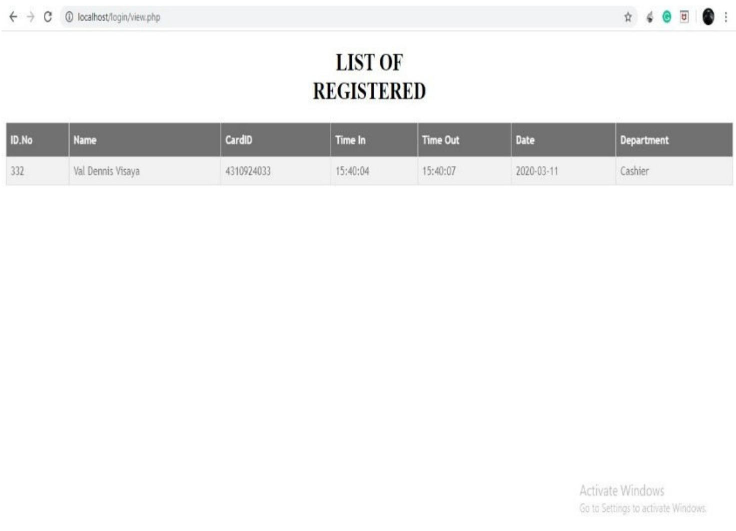

Fig 8. Display of registered users

As shown in **Figure 8**, the system's web interface displays a comprehensive log of data captured from the RFID reader during user interactions. The tabular format organizes multiple fields essential for access control and monitoring. From left to right, the columns include the **user identification number**, **full name**, and **card identification number**, which are critical for verifying each user's unique RFID tag. Following these are the **Time-In** and **Time-Out** columns, which record the exact moments a user enters and exits the parking facility. The **Date** column documents the specific day—formatted as year-month-day—on which each access event occurred. Lastly, the **Department** column indicates the user's assigned unit or organizational affiliation. These collected data elements are essential for system authentication, ensuring that only authorized users are permitted entry and exit, while also maintaining a secure and traceable access history.

To validate the system's operational performance, a series of controlled test runs were conducted in a simulated parking environment. The evaluation focused on key performance indicators, including vehicle throughput, RFID scan success rate, and system responsiveness.

Test Results:

During the peak simulation phase, the Smart Car Parking System demonstrated the ability to process an average of 12 vehicles per minute, equivalent to approximately 5 seconds per vehicle, under optimal conditions with continuous RFID scans and no user-induced delays. This processing time encompassed the complete cycle of RFID tag detection, database verification, and servo motor-triggered gate actuation. Additionally, the RFID scan success rate was measured by conducting 100 scanning attempts, of which 98 were successfully authenticated and processed, resulting in a 98% success rate. The two failures encountered were attributed primarily to incorrect tag orientation or the tag being held outside the effective reading distance, which ranges from approximately 2 to 3 centimeters. The average time between successful RFID detection and barrier gate actuation was recorded at 1.8 seconds, reflecting the programmed servo delay and the server's data processing response time.

Despite these promising results, several system limitations were identified. First, the system is designed to assign only one RFID tag per user, which limits its applicability in scenarios where a user may operate multiple vehicles. Second, the system relies heavily on the stability of the wireless network connection facilitated by the ESP8266 Wi-Fi module; interruptions in connectivity may delay or prevent access authorization. Third, the system does not include features to detect the availability of parking slots, reducing its scalability and efficiency in large parking areas where space allocation is critical. Lastly, the system lacks redundancy mechanisms such as offline authentication protocols or manual override options, making it vulnerable during power outages or server failures. These constraints, while not critically affecting basic functionality, highlight areas for future enhancement to improve system robustness and adaptability in real-world deployments. Table 1 below shows the detailed interpretation of the results.

Table 1. Performance Metrics and System Limitations of the RFID-Based Smart Parking System

Category	Description
Vehicle Throughput	Average of **12 vehicles per minute** (approximately 5 seconds per vehicle) under optimal conditions. This includes RFID detection, verification, and gate actuation.
RFID Scan Success Rate	**98% success rate** based on 100 scanning attempts. Failures were due to improper tag orientation or holding the tag beyond the effective 2–3 cm range.
Gate Response Time	Average of **1.8 seconds** between RFID tag scan and gate actuation, aligned with servo motor delay and server response time.
Limitation 1 – Single-Tag Constraint	The system supports **only one RFID tag per user**, which is limiting for users with multiple vehicles.
Limitation 2 – Wi-Fi Dependency	Relies on **stable Wi-Fi** using ESP8266. Connectivity issues can cause **delays or access failure**.
Limitation 3 – No Slot Detection	The system **does not monitor parking slot occupancy**, reducing its effectiveness in large-scale environments.
Limitation 4 – No Redundancy	Lacks **offline authentication or manual override**, which can hinder access during **power or server failures**.

IV. SUMMARY, CONCLUSION & RECOMMENDATIONS

Summary

Following a series of rigorous experiments and systematic evaluations, the Smart Car Parking System has been successfully developed and tested. The system demonstrates effective performance in managing vehicle entry and

exit within a parking facility with minimal human intervention. It fulfills the primary objective of the project—**to provide users with a seamless, secure, and automated parking experience**.
Technically, the Capstone Project aimed to deliver a practical and efficient solution for institutions such as schools, commercial centers, and corporate campuses in need of improved vehicular monitoring. By utilizing **Radio Frequency Identification (RFID)** technology, the system minimizes dependency on manual labor and enhances security through automated identification and logging mechanisms.

Conclusion

Based on the results of the study, the researchers concluded that the proposed Smart Car Parking System can serve as a scalable and adaptable solution for various organizations seeking to manage vehicular traffic efficiently. While alternative systems may offer more advanced embedded hardware, this project proves that **a reliable security framework can be achieved through proper identification protocols and centralized access control**.

The study emphasizes that safeguarding an organization's premises requires robust and technology-driven mechanisms, particularly when it involves the movement of private and public vehicles. Implementing RFID-based solutions provides a **layer of security and traceability** that is essential in mitigating unauthorized access and ensuring organizational safety.

Recommendations

For future development and enhancement of the Smart Car Parking System, the researchers recommend the following:

1. **Integration of Payment Features**: Incorporating postpaid or prepaid card-based payment systems could add a valuable service layer, enabling the system to function in revenue-generating environments such as malls or pay-parking establishments.
2. **Parking Slot Monitoring**: Installing occupancy sensors in individual parking slots would enable the system to detect and display available parking spaces, further improving traffic flow and user convenience.

ACKNOWLEDGMENT

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Appreciation is extended for the collective guidance, encouragement, and technical expertise that contributed to the realization of the objectives of this study. Recognition is also given to the unwavering source of strength and inspiration that enabled the researcher to persevere through challenges and accomplish this undertaking.

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