Sri Lanka Institute of Information Technology

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RFID-based Smart Vehicle Parking System

Proposal Document

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01. Introduction

In the present, as the number of urban vehicles increases, vehicle parking management has become a challenge. In many cities, institutions and commercial areas, limited parking capacity and outdated management practices cause congestion, wasted time and driver frustration. Traditional parking systems typically rely on manual ticketing or paper-based tokens, which are not only time-consuming but also prone to human error and misuse. As a result, drivers face difficulties in finding available parking slots.

Advancements in IoT (Internet of Things) and embedded system technologies have created new opportunities to transform conventional parking systems into smart, automated solutions. By integrating RFID or NFC technology for automatic vehicle identification and ultrasonic sensors for real-time slot detection, parking operations can become faster, more reliable, and more transparent. Such systems eliminate manual effort, reduce human error, and provide a seamless experience for both users and administrators. To reduce both traffic congestion and time-wasting, the RFID system has been introduced. And this system can identify available parking spaces.

RFID (Radio Frequency Identification) technology allows vehicles to be automatically identified using RFID tags and readers. Each Vehicle is given a unique RFID tag that stores information about the vehicle and the owner. When the vehicle enters or exits the parking slot a RFID reader detects the tags and updates the system automatically. This system helps in faster vehicle entry and exit, and performs automatic fee calculation. By implementing this system, the entire parking process can be made quicker, safer, and more transparent. Furthermore, the automation of the cost calculation and record management will help reduce operational costs and human errors.

02. Problem and Motivation.

Vehicle parking is a growing problem in most cities. As the number of vehicles increases each year, the available parking space remains limited. Poor urban planning, lack of awareness, and inefficient management of existing parking areas have made parking one of the most common urban challenges today.

Conventional parking systems are based on manual operation in terms of issuing tickets, directing vehicles to parking slots, and determining charges. These are not only laborious but expensive. In most parking systems, real-time information concerning the availability of parking slots is not provided. As a result, drivers are forced to wait in vain for free slots. Inevitable Traffic congestion occurs in these systems.

In addition to these requirements, a human-operated parking system remains labor-intensive or requires continuous human interaction. As a result, there are increased costs involved. Moreover, there is a risk of human error in these systems. These could include errors in billing or unauthorized entries. The lack of automation or smart monitoring in these parking systems leads to accuracy issues and inefficient use of available resources. In other words, there is a huge demand for a smart parking system based on technology.

The motivation for developing an RFID Smart Vehicle Parking System is the growing need for efficient, automated, and intelligent parking systems. The increasing rate of urbanization globally, coupled with increased vehicle ownership, has made parking slots a scarce resource. As a result, roads are congested due to increased vehicles. Manual parking systems are inefficient. They are expensive, involving human labor to manage tickets, slots, and charges. There is a need to use intelligent technology like IoT to address these problems.

- Urban Parking Issues: As per global transportation studies, a major cause of congestion in cities around the world is due to drivers looking for available parking spots. Inadequate parking system management leads to fuel waste, wasted time, and emissions. Designing a smart parking solution can thus prove an efficient way to reduce congestion on roads and maximize the use of available parking spots.
- Technological Advancements: Recent advances in IoT (Internet of Things), RFID identification technology, and sensor-controlled automation make possible the development of smart parking systems that can monitor and control vehicles in real-time. With these advances, the system can be designed to enable automatic entry and exit point detection for vehicles entering or leaving parking slots, as well as park charges computation.
- Economic Benefits: In manual parking systems, there are labor costs involved since several parking participants are needed. With the adoption of an automated system for parking facilities, these labor costs are greatly reduced. Also, there are accuracy benefits in terms of calculating costs.

- Environmental and Social Impact: Unnecessary idling or movements that occur in parking lots contribute to fuel waste and air pollution. With the system's real-time availability status and fast entry and exit processing, these problems are greatly eliminated or minimized. Moreover, increased conveniences provided by automation mean increased adoption or shift to smart and sustainable ecosystems in cities.

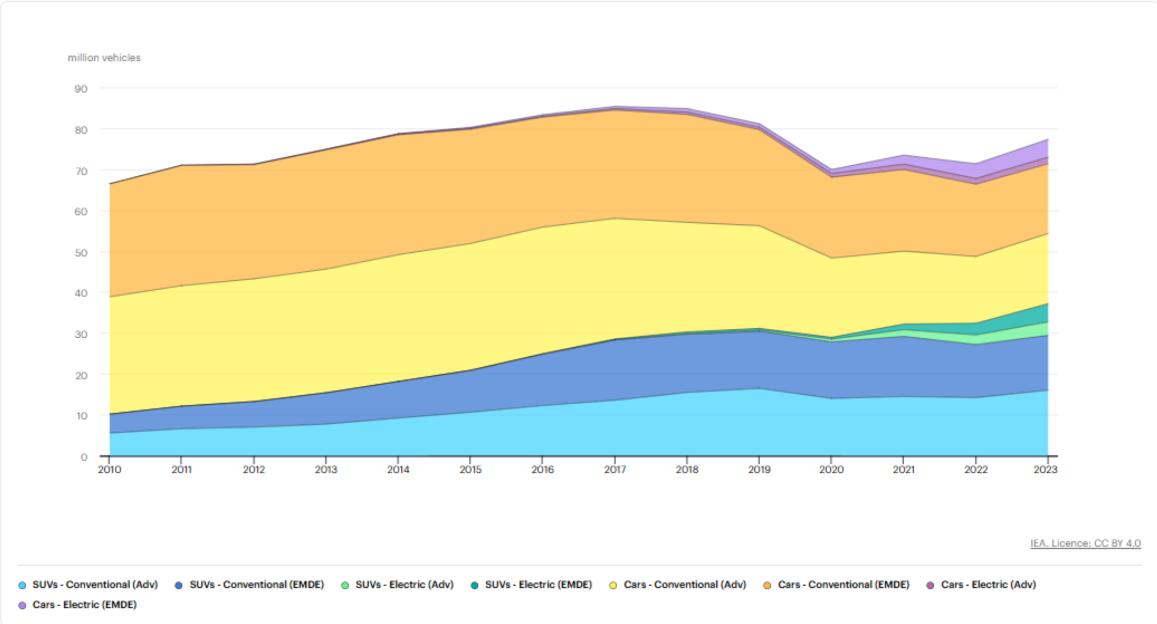

Figure 1: IEA (2024), New car registrations by size and powertrain, 2010-2023, IEA, Paris

03. Aim and Objectives.

The "MIRAI Smart Parking System" has been proposed to create an intelligent, fully automated parking system for vehicles using RFID technology along with ultrasonic sensors to deliver real-time status information related to parking slot availability, automated control of gates, and efficient management of parking charges. With cutting-edge technology integration related to IoT communication, embedded systems, and online data observation, the system intends to enable fast, secure, and convenient parking with minimal human interference.

It was intended to automatically detect vehicles with RFID cards, manage gate access, check slot status, and determine parking fees based on the duration parked. The solution was intended to address efficiency enhancement, user convenience, and security related to vehicles parked in this parking system.

Below are some objectives which define the main requirements and implementation steps or milestones to achieve for the design and implementation of the MIRAI Smart Parking System.

1. Automated Access Control - Using an RFID tag, the authorized user's vehicle can be detected for entry and exit, and the gate is automatically opened and closed
2. Real-time monitoring - Providing drivers with real-time information about available parking spaces through a website to help them find an available parking spot quickly.
3. Security Enhancement - The enhanced security system allows only authorized vehicles to enter through RFID and records the entry and exit times of each vehicle.
4. Handle Payment - The RFID parking system automates fee collection by reading the tag upon exit, calculating the duration of stay, and automatically deducting the parking fee from the user's linked prepaid account.
5. Time Saving - Through the entry control process, the entry and exit of vehicles is monitored and recorded within a short period of time.
6. Data Management and Reporting - To store or retain information regarding vehicles, parking sessions, or payments in a database that can easily be retrieved or reported on by administrators.
7. User Convenience - Enhancing user experience by providing an interface that makes it easier for drivers to check slots, parking charges, and session histories using the website.
8. System Reliability & Performance - To enable the system to function correctly and reliably by testing its functionality related to readings from sensors, communication with the backend, and updating the dashboard.
9. Future Scalability and Integration - In designing the system to enable scalability to allow integration into mobile apps, cloud databases, or payment gateways to enable expansion to larger parking areas.

04. System Diagram

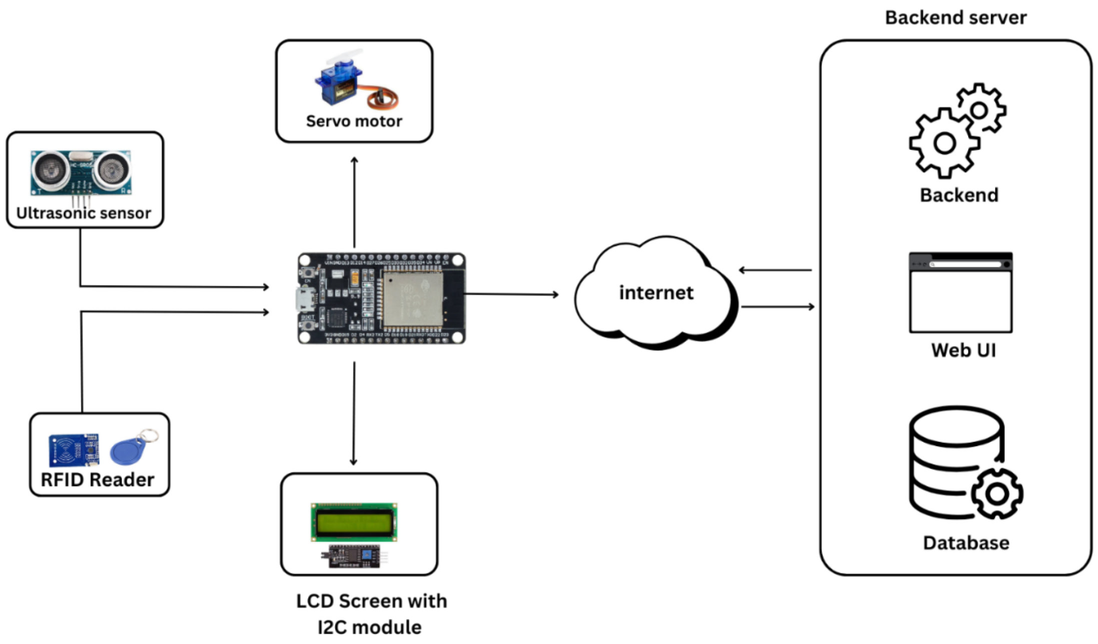

Figure 2: System Diagram

05. Methodology

Diverse methods, tools, and technology will be used to achieve efficient development, testing, and implementation for the "MIRAI Smart Parking System."

It would include everything from choosing hardware to developing software, designing interfaces for website functionality, testing systems, to evaluating system performances.

1. Requirement Analysis and Planning
    - Objective: To collect data related to system requirements and to devise a plan regarding design, development, and implementation for smart parking system implementation.
    - Methods:
        - Stakeholder Discussions: Organize conversations with drivers, parking managers, and supervisors to learn more about parking issues encountered today and what functionality is desired.
        - Use Case Analysis: Identifying interactions involving users like entering vehicles, slot detection, pricing calculations, or updating online dashboards.
        - Requirement Documentation: Prepare a Software Requirement Specification, which details both functional & non-functional requirements, data flow requirements, and project scope.
    - Tools:
        - Google Forms: User requirements collection or feedback.

    - Microsoft Word or Google Docs: These are used for creating requirement specifications.
2. System Design
    - Objective: To design the architecture, hardware components, and user interfaces of our system based on requirements.
    - Methods:
        - System Architect Design: Work on block diagram illustrations that address interactions between hardware components (RFID Reader/Sensors/ESP32 module), backend components (web dashboard), or database components.
        - Hardware Design: Select sensors, microcontrollers, and other components for identifying vehicles and gate control actuators.
        - Software Design: Create backend and database schemas to accommodate data related to vehicles, slots, sessions, and cost.
        - User Interface Prototyping: Create a design for user interfaces to display slot availability and parking charges to both users and administrators.
    - Tools:
        - Draw.io: These are used to create system architecture or flow diagrams.
        - Figma: For wireframing & UI prototyping.
        - Microsoft Visio: For designing database schemas or data flows.
3. Development
    - Objective: Implementing both hardware and software parts of the system based on design requirements.
    - Methods:
        - Hardware Development: Make the ESP32 microcontroller read RFID tags, collect data from the sensors, and transmit them to the backend using Wi-Fi and add ultrasonic sensors for slot detection and servo motors for automatic gate control
        - Backend Development: Design a backend using Spring Boot to handle requests, store data, and complete cost calculations and add RESTful APIs to enable interactions between hardware components.
        - Front-end development: Design a web-based dashboard using HTML, CSS, and JavaScript to show real-time information regarding slot availability, vehicle information, and parking charges.
    - Tools:
        - Arduino IDE: Arduino development environment used for coding ESP32 to check functionality.
        - VS Code: As the primary IDE for development.
        - Git/GitHub: For version control, collaboration, and code repository management.
        - Spring Boot Framework: For implementing backend logic, REST API development, and calculating cost.

4. Testing and Quality Assurance
    - Objective: Ensuring that system functionality occurs correctly, reliably, and effectively in identifying and correcting system flaws.
    - Methods
        - Unit Testing: Testing individual modules like RFID detection, reading sensor values, or calculating cost.
        - Integration Tests: These are used to test communication between hardware components like ESP32 or other sensors and software components like
        - System Testing: Test real-world parking conditions with multiple vehicles to validate gate function operation, time stamping, slot status updating, and cost accuracy.
        - User Acceptance Testing: Give test users (drivers/admins) access to the system so they can evaluate its functionality.
    - Tools:
        - Postman: For testing REST APIs
        - Arduino Serial Monitor: For debugging or monitoring data readings coming from sensors or RFID.
5. Deployment and Integration
    - Objective: Install the system within the target environment to enable correct functionality.
    - Methods:
        - Backend Deployment**:** Host the Spring Boot server locally or on cloud service
        - Database Setup: Set up MySQL database authentication. Make MySQL database backups.
        - Hardware Integration: Add ESP32 boards, sensors, RFID readers, and motors to a hardware prototype or parking model.
        - Web Application Integration: The dashboard needs to be integrated with the live backend API to enable real-time slot and cost monitoring.

06. Evaluation Method

The evaluation of the "MIRAI Smart Parking System" - RFID and ultrasonic sensor-based smart vehicle parking system will be carried out through a structured software and hardware testing process. The system will be evaluated at multiple testing levels, including unit testing, integration testing, system testing, user acceptance testing, and performance and reliability testing, to ensure that each component functions correctly and that the complete system meets all performance requirements.

1) Unit testing - To verify each individual component functions correctly in isolation. We verified the RFID reader, Ultrasonic sensor, ESP32 firmware software-level, and Motor individually, achieving the expected outcomes.
   a. Test Cases: Conduct a series of test cases to validate each feature, including **the** RFID **reader,** by scanning registered and unregistered tags to verify accurate identification. Test the ultrasonic sensors by placing and removing a vehicle to confirm accurate detection of distance. Test the servo motor by sending open/close commands to ensure proper gate control
   b. Accuracy Checks: Compare each module's outputs with expected results. For instance, test 10 RFID scans and ensure at least 9 are successful or compare ultrasonic readings with manual distance checks.
   c. Expected Outcome: Each module functions independently and produces accurate, reliable results before integration.
2) Integration Testing - To ensure that modules communicate and work correctly
   a. Test Cases - Verify that ultrasonic sensors send real-time slot data to the backend and that the web interface updates instantly, ensure that the servo motor (gate) responds accurately to backend verification after an RFID tag is scanned.
   b. Communication Validation - Monitor data transfer between modules using serial monitor or backend logs to ensure no data loss or communication errors occur.
   c. Expected Outcome: All components exchange data seamlessly and operate in sync without delay or miscommunication.
3) Security Checks - To verify system protection against unauthorized access and misuse.
   a. Authentication Testing: Ensure only registered RFID tags can trigger gate operations and system responses.
   b. API and Backend Security: Test backend endpoints for access control Use mock attacks to verify that unknown requests are denied.
   c. Data Privacy and Protection: Ensure user and vehicle data stored in the database cannot be accessed or modified without authorization.
4) Data Integrity Testing – To ensure accuracy and consistency of stored data.
   a. Database Validation: Verify that each parking session record (entry/exit time, slot, cost) is accurate and unique. Ensure no duplicate or missing entries occur.
   b. Data Accuracy**:** Cross-verify data displayed on the web dashboard with database records for consistency.
   c. Expected Outcome: All stored data remains accurate, consistent, and synchronized with system activities.

5) System Testing - To test the complete integrated system to ensure it meets all functional and non-functional requirements.
    a. Simulation Testing: Conduct a real-world parking simulation with multiple vehicles entering and exiting to verify that the entire system operates as expected.
    b. Functional Validation: Ensure the web dashboard displays all real-time updates — including available slots, parked vehicles, and cost information.
6) Performance and Reliability Testing – To assess the system's speed, stability, and consistency under different conditions.
    a. Response Time Analysis: Measure the time taken for key actions such as RFID scans and gate opens, then dashboard update.
    b. Accuracy and Stability Tests: Test RFID reader accuracy over 50+ scans, Test ultrasonic sensor reliability through continuous cycles of parking and removal
    c. Stress and Load Testing: Simulate multiple vehicles entering and exiting simultaneously to evaluate how the backend handles concurrent operations without data loss or delay.

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