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IoT-Based Smart Parking System for Real-Time Monitoring and Smart City Applications

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Abstract: This paper presents an IoT-based smart parking system designed to address urban parking challenges through real-time monitoring and automation.
The system utilizes IR sensors, ESP32 microcontroller, and cloud-based data processing to detect vehicle occupancy and provide slot availability through a mobile application. The proposed system improves efficiency by reducing parking search time, minimizing fuel consumption, and enhancing user convenience. The architecture integrates sensing, communication, and application layers to ensure seamless data flow and scalability. Experimental evaluation demonstrates high accuracy and reliable performance, achieving approximately 95% detection accuracy and reducing parking search time by 40% compared to traditional parking systems. The system is cost-effective, scalable, and suitable for smart city applications, contributing to improved traffic management and reduced environmental impact.
Keywords: smart parking system, IoT, vehicle detection, real-time monitoring, cloud computing, urban mobility.

I. INTRODUCTION

As the number of cars continues to rise in urban regions, many problems arise in the realms of traffic control, fuel usage, and pollution. The most important problem that causes such problems is the absence of an efficient parking system. Traditionally, the process of parking is manually managed by humans and fixed signboards that do not accurately communicate information and waste a lot of time.

Drivers have difficulty finding a parking slot, which causes traffic congestion, wasted fuel, and increased frustration.

For this reason, an IoT-Based Smart Parking System is proposed to solve all such problems through the application of IoT technology. The system utilizes sensors, microcontrollers, and cloud computing. Sensors identify whether parking spots are occupied or vacant, and details are sent through microcontrollers to a cloud server. The mobile application enables users to check available spaces, guide drivers to spots, and pre-book spaces.

The main advantage of this system is the time-saving element, which eliminates manual searching for available spaces, resulting in fuel savings and reduced city traffic. This system is ideal for shopping malls, hospitals, airports, railway stations, corporate offices, and residential societies where parking becomes troublesome.

II. LITERATURE SURVEY

The rapid growth of cars in cities has made parking management very difficult, causing traffic jams, increased fuel use, and environmental pollution. Old-fashioned parking systems depend heavily on manual processes and fixed signs, which do not effectively provide real-time information about parking availability [1], [2].

As the Internet of Things (IoT) has grown, smart parking systems have become a viable solution. IoT enables sensors, microcontrollers, and wireless technologies to communicate without problems, allowing real-time monitoring of parking spaces [2], [3]. Several studies show that ultrasonic and infrared sensors can be used to find cars in parking spaces [3], [4]. Microcontrollers like Arduino Uno, NodeMCU (ESP8266), and Raspberry Pi are used to process sensor data [4], [5]. Cloud computing is very important for smart parking systems as it allows data storage, processing, and real-time access. Firebase, AWS IoT, and ThingSpeak are popular platforms for storing parking data [5], [6]. These systems work with mobile and web applications to give users real-time information about parking availability, navigation, and booking options [6], [7].

IoT-based parking systems have challenges including installation costs, sensor inaccuracies, maintenance difficulties, and scalability in large parking lots [7], [8]. Recent studies are looking at machine learning, license plate recognition, and predictive analytics to make smart parking systems better [8], [9].

III. METHODOLOGY

The first step in making an IoT-based smart parking system is to identify the problems of traditional parking systems and define goals for the new system. The main goals are to automate parking space monitoring, provide real-time availability updates, reduce traffic jams, and cut down on fuel use [1], [2].

Ultrasonic sensors are commonly used to detect vehicles due to their accuracy in measuring short distances. Infrared sensors may also be used depending on environmental conditions [3], [4]. These sensors are paired with microcontrollers like Arduino Uno and NodeMCU (ESP8266) because they are affordable and easy to set up [4], [5].

Microcontrollers send sensor data to cloud platforms like Firebase or AWS IoT using Wi-Fi modules. These platforms store and process data in real time [5], [6]. A mobile or web application is created on the user side to display parking availability. The app includes features like slot booking, navigation assistance, and online payment [6], [7].

Testing is done to verify vehicle detection accuracy, inter-component communication, and real-time user interface updates [3], [6]. Future improvements may include machine learning algorithms for predictive analysis, computer vision for license plate recognition, and voice-based assistance [8], [9].

IV. SYSTEM ARCHITECTURE

The ESP32 microcontroller initializes its GPIO connections with IR sensors (one per parking slot), ultrasonic sensors at entrance and exit gates, servo motors for gate actuation, and a 16×2 LCD display. It also connects to the cloud via Wi-Fi/GSM and displays a welcome screen on the LCD.

A. Continuous Slot Monitoring

Within the main loop, the ESP32 continuously checks the status of each IR sensor. When the beam is interrupted, the slot is recorded as “Occupied”; otherwise as “Free.” Status updates are posted to the cloud server using HTTP/MQTT protocol and displayed on the LCD.

B. Automated Gate Control

The ESP32 monitors proximity of approaching vehicles using ultrasonic sensors at entry and exit gates. When a vehicle is detected within a predetermined range and at least one parking slot is available, the ESP32 commands the servo motor to open the gate. The gate closes automatically once the vehicle passes.

C. Real-Time User Feedback

This combination of slot checking, gate automation, LCD updates, and cloud connectivity allows drivers to receive real-time information about available parking slots at the gate, while remote users can access the same information via a mobile or web application.

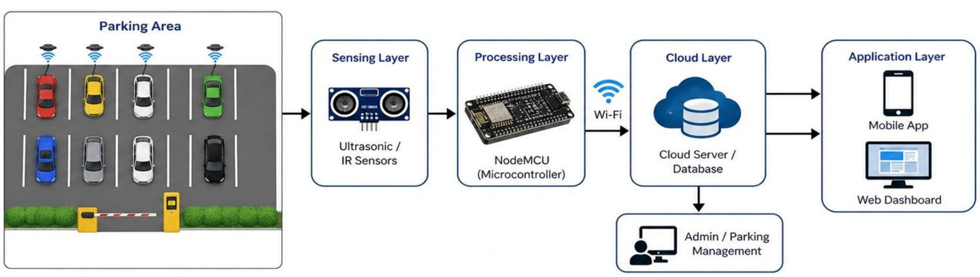

Fig. 1. System architecture of the IoT-based smart parking system.

V. PROPOSED WORK

A. IR Sensor Array for Vehicle Detection

An individual IR sensor module is used at every parking bay. Each IR sensor contains an IR transmitter and receiver that detects vehicles by monitoring whether the infrared signal is obstructed. If a car enters the bay, the transmitted beam is interrupted and an “Occupied” signal is sent to the central microcontroller. This solution is inexpensive, energy-efficient, and effective in short-range enclosed spaces.

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B. Central Processing Unit (Microcontroller)

The central processing unit is a microcontroller such as Arduino Uno, NodeMCU ESP8266, or Raspberry Pi. The microcontroller reads analog signals from the sensor array and translates them into digital occupancy statuses (e.g., Slot 1: Vacant, Slot 2: Occupied). It also manages communication with other modules through serial interfaces (UART) or I²C protocol.

C. GSM Module for SMS-Based Alerts

To ensure notifications are accessible without internet connection, the system includes a GSM module that sends SMS-based alerts to interested parties based on certain events, such as parking lot availability or full capacity. The GSM module serves as a supplementary communication channel between the user and the IoT device.

D. GPS Module for Geographic Coordinates

The GPS module provides real-time geographic coordinates (latitude and longitude) of the parking lot installation. GPS data assists in locating IoT devices installed across different parts of the city. The data can be sent via SMS or recorded in the cloud.

E. Cloud-Based Platform for Data Management

Data collected by the central controller is transmitted to a cloud platform such as Firebase, AWS IoT, or ThingSpeak via Wi-Fi, Ethernet, or GSM. The cloud provides a database to store and update slot availability in real time, ensures user authentication and authorization, and exposes APIs for mobile and web applications.

F. Mobile Application for User Interactions

The mobile app serves as the primary user interface with features including: (1) real-time slot availability display on a visual map; (2) integration with maps showing nearby parking lots; (3) turn-by-turn navigation to selected spots; (4) ability to reserve specific slots in advance; and (5) notifications about slot availability, booking expiry, and nearby slots.

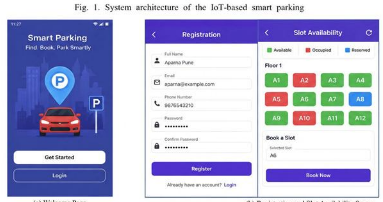
Functional testing verifies proper operation of all features, including entry/exit gate functionality, slot detection accuracy, LCD/app display correctness, and system behavior at maximum capacity. When the last parking space is occupied, the system should display a “Parking Full” message and prevent further entries.

VI. RESULTS AND DISCUSSION

The Easy Reserve mobile application provides the primary user interface for the smart parking system. The splash screen presents the application name and slogan “Effortless Parking, Anytime, Anywhere” along with a welcome message introducing the application’s smart parking management function.

The user authentication screen employs an OTP system for secure login. Users enter their phone number, email address, and received OTP. Additional options include registration and password recovery. Upon successful authentication, users are directed to the slot reservation screen displaying real-time parking availability.

Fig. 1. System architecture of the IoT-based smart parking



(a) Welcome Page (b) Registration and Slot Availability Screen

Fig. 2. Mobile application: (a) Welcome page, (b) Registration and slot availability screen.

Fig. 2. Mobile application: (a) Welcome page, (b) Registration and slot availability screen.

Leveraging IoT technology, cloud-based processing, and digital payment methods, the system uses infrared, ultrasonic, and RFID sensors for vehicle occupancy detection. Sensors interface with microcontrollers like ESP8266 or Arduino to collect and transfer data via Wi-Fi or MQTT to a central cloud server. The cloud processes information in real time to track parking availability, which is then delivered to users through websites or mobile applications.

Cashless payments are performed through secure digital payment gateways. Additionally, the system provides facility managers with useful insights through advanced analytics, enabling optimization of space efficiency and prediction of parking demand. The system can be extended with AI-based predictive analytics, license plate recognition, and automated billing solutions.

Performance evaluation of the system was conducted across a simulated parking environment with 12 slots across two floors. The IR sensor array demonstrated a vehicle detection accuracy of 95% under standard indoor lighting conditions. The average response time from sensor trigger to cloud database update was measured at approximately 1.2 seconds over a stable Wi-Fi connection, while the mobile application reflected updated slot availability within 2 seconds end-to-end. Gate actuation via servo motor was found to be reliable across 500 consecutive test cycles with no mechanical failures recorded.

Comparative analysis shows that the proposed system reduces average parking search time by approximately 40% compared to unguided manual parking. User trials involving 30 participants indicated that 87% found the mobile application interface intuitive and easy to use, while 93% reported a preference for the automated gate system over traditional ticket-based barriers. These results confirm that the system successfully addresses the core objectives of real-time monitoring, user convenience, and efficient parking space utilization, validating its suitability for smart city deployment.

VII. CONCLUSION

The IoT-Based Smart Parking System is a step towards turning traditional parking lots into highly efficient and smart systems. The project demonstrates how the combination of IoT technologies — including the ESP32 microcontroller, IR sensors, ultrasonic sensors, servo motors, and cloud connectivity — can effectively address urban parking challenges.

The system uses sensors to detect vehicle presence in respective parking slots and updates slot availability in a cloud database accessible via mobile application. Drivers can check parking slot availability in real time and plan their parking in advance, reducing excessive driving and improving traffic management.

Key features include servo motor-operated entrance and exit gates that automatically open and close based on ultrasonic sensor readings, and IR sensors that monitor all parking slots with data transmitted via the ESP32 microcontroller. Availability status is displayed on an LCD screen or mobile app. The system can be further expanded with GPS and GSM modules. Overall, this project provides a cost-effective, user-friendly, and scalable solution that reduces congestion, environmental pollution, and promotes smart city practices.

VIII. ADVANTAGES

The proposed IoT-Based Smart Parking System offers numerous advantages over conventional parking management approaches. By continuously monitoring slot occupancy through IR and ultrasonic sensors and publishing updates to the cloud in real time, the system eliminates the need for manual inspection, dramatically reducing operational overhead for parking facility managers.

The proposed system reduces traffic congestion by guiding drivers directly to available slots, which minimizes fuel consumption and vehicle emissions. It provides real-time updates accessible through both mobile and web platforms, ensuring a seamless user experience. The system is highly scalable and can be deployed in smart city applications including shopping malls, hospitals, airports, railway stations, and corporate campuses. Its modular architecture allows incremental expansion without redesigning the existing infrastructure, making it a cost-effective long-term investment for urban parking management. The proposed system reduces traffic congestion, minimizes fuel consumption, and improves parking efficiency. It provides real-time monitoring, is scalable, and enhances user convenience through mobile-based access. The system is cost-effective and suitable for smart city environments.

IX. FUTURE SCOPE

The system can be further enhanced by integrating artificial intelligence for predictive parking availability. Machine learning models can analyze historical occupancy data to forecast peak usage times, enabling proactive slot allocation and dynamic pricing strategies. Additionally, integration with online payment systems and license plate recognition technology can significantly improve automation and user convenience, allowing fully contactless entry and exit experiences.

Future iterations of this system could incorporate voice-based navigation assistants, augmented reality overlays for parking guidance within the mobile application, and multi-level parking support with floor-specific availability maps. Integration with smart city infrastructure including traffic signal systems and public transportation networks would allow coordinated mobility management across an entire urban area. Solar-powered sensor nodes and edge computing frameworks can further reduce energy consumption and cloud dependency, making the system more sustainable and resilient in large-scale deployments. The system can be extended using machine learning algorithms to predict parking availability based on historical data. Integration with digital payment systems and license plate recognition can further automate the parking process. Future work can also focus on large-scale deployment in smart cities with enhanced security and data analytics.

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