



IoT-Enabled Smart Parking System with Slot Monitoring

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Abstract: Parking congestion in urban and semi-urban areas has become a critical issue due to the rapid increase in vehicle population and inefficient parking management. This paper presents the design and implementation of an IoT-enabled smart parking system for both indoor and outdoor organized parking areas. The proposed system uses ultrasonic sensors installed at each parking slot to detect vehicle occupancy. An ESP32 microcontroller acts as a zone controller, collecting sensor data and transmitting it via Wi-Fi to a cloud-based backend. The system employs a Node.js server for data processing and MongoDB Atlas for cloud data storage. A web-based dashboard developed using React and Vite provides real-time visualization of parking slot availability using a grid-based layout. Experimental results show that the proposed system provides accurate real-time slot monitoring, reduces parking search time, and improves parking space utilization. The system is scalable, cost-effective, and suitable for deployment in smart parking environments such as malls, campuses, hospitals, and public parking facilities.

Keywords— Smart Parking, IoT, Ultrasonic Sensor, ESP32, MongoDB Atlas, Node.js, Web Dashboard.

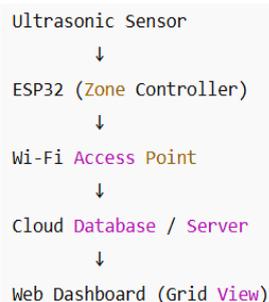
I. INTRODUCTION

Rapid urbanization and the growth in vehicle ownership have significantly increased parking-related challenges in cities. Drivers often spend a considerable amount of time searching for vacant parking spaces, leading to traffic congestion, fuel wastage, and increased pollution. Conventional parking systems rely on manual supervision and lack real-time visibility of parking slot availability.

Recent advancements in the Internet of Things (IoT) enable intelligent parking solutions through real-time data collection, wireless communication, and cloud-based processing. This paper focuses on the implementation of a smart parking system that provides real-time slot-level monitoring using low-cost sensors, cloud infrastructure, and a web-based visualization platform. The system is designed to support both indoor and outdoor organized parking environments.

II. SYSTEM OVERVIEW

The proposed smart parking system follows a modular and scalable architecture. Each parking slot is equipped with an ultrasonic sensor for vehicle detection. Sensors are connected to an ESP32 microcontroller that functions as a zone





controller. The ESP32 transmits occupancy data to a cloud server over a Wi-Fi network. The backend server processes the data and stores it in a cloud-hosted MongoDB Atlas database. A web dashboard displays real-time parking availability to users.

III. HARDWARE COMPONENTS

A. Ultrasonic Sensor

Ultrasonic sensors are used to detect the presence of vehicles in parking slots by measuring the distance between the sensor and the object. If the measured distance is below a predefined threshold, the slot is considered occupied. Ultrasonic sensors are cost-effective, reliable, and suitable for both indoor and outdoor parking environments.

B. ESP32 Microcontroller

The ESP32 is used as a zone controller due to its built-in Wi-Fi capability, low power consumption, and sufficient processing power. It collects sensor readings from multiple parking slots and sends occupancy data to the cloud server.

IV. SOFTWARE COMPONENTS

A. Backend Server (Node.js)

The backend is implemented using Node.js and handles the following tasks:

1. Receiving sensor data from ESP32 devices
2. Processing and validating slot status
3. Updating real-time parking data in the database
4. Providing REST APIs for frontend access

B. Cloud Database (MongoDB Atlas)

MongoDB Atlas is used as the cloud-hosted NoSQL database to store:

1. Slot ID
2. Zone ID
3. Slot status (occupied/free)
4. Timestamp of last update

MongoDB's document-based structure enables easy scalability and real-time updates.

C. Frontend Web Dashboard

The frontend is developed using **React** with **Vite** for fast build and deployment. The dashboard displays a grid-based parking layout where:

1. Green indicates free slots
2. Red indicates occupied slots

The dashboard fetches live data from the backend using REST APIs.

V. SLOT DETECTION ALGORITHM

The system uses a threshold-based detection algorithm.

Algorithm Steps

1. Read distance value from ultrasonic sensor.
2. If distance < threshold → Slot Occupied.
3. Else → Slot Free.



4. Send updated slot status to backend server.
5. Store data in MongoDB Atlas.
6. Update web dashboard in real time.

Mathematical Representation

$$SlotStatus = \begin{cases} 1, & \text{if distance} < \text{threshold} \\ 0, & \text{otherwise} \end{cases}$$

VI. IMPLEMENTATION AND WORKING

The system is divided into parking zones, with each ESP32 handling multiple slots. Sensor data is periodically transmitted over Wi-Fi to the backend server. The backend updates the cloud database, and the frontend reflects changes instantly. The architecture supports easy expansion by adding more zones without major changes to the system.

VII. RESULTS AND PERFORMANCE ANALYSIS

The implemented system was tested in a prototype parking environment. Observations include:

1. Accurate slot detection under controlled conditions
2. Real-time updates with minimal delay
3. Reduced parking search time
4. Stable performance for both indoor and outdoor setups

VIII. ADVANTAGES OF PROPOSED SYSTEM

1. Low-cost and scalable design
2. Real-time monitoring
3. Cloud-based access
4. Easy integration with future features
5. Suitable for smart city applications

IX. LIMITATIONS

1. Dependence on Wi-Fi connectivity
2. Sensor accuracy affected by extreme weather conditions
3. Requires proper sensor placement

X. FUTURE ENHANCEMENTS

1. Slot reservation system
2. Online payment integration
3. Mobile application support
4. AI-based number plate recognition
5. LoRaWAN integration for large outdoor parking

XI. CONCLUSION

This paper presented the design and implementation of an IoT-enabled smart parking system using ultrasonic sensors, ESP32, cloud infrastructure, and a web-based dashboard. The system provides accurate real-time parking information, reduces congestion, and improves parking efficiency. The proposed architecture is cost-effective, scalable, and suitable for deployment in both indoor and outdoor organized parking environments.

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