INTERNATIONAL JOURNAL OF ADVANCED INNOVATIVE TECHNOLOGY IN ENGINEERING

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IoT-Based Smart Parking System for Real-Time Space Management using Sensor Networks

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Article History

Received on: 20 July 2026
Revised on15 Aug 2026
Accepted on: 20 Sept 2026
Keywords: Smart Parking System, Internet of Things (IoT), Sensor Networks, Real-Time Monitoring, Embedded Systems, Smart Cities, Automation, Vehicle Detection

e-ISSN: 2455-6491

DOI: 10.65809/IJAITE/26/v03sp02/096

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ABSTRACT

Rapid urbanization has intensified the need for efficient parking management, contributing to traffic congestion, increased fuel consumption, and environmental pollution. This study presents an Internet of Things (IoT)-enabled smart parking system designed to optimize parking-space utilization through real-time monitoring and intelligent data processing. The proposed framework integrates sensor networks, embedded systems, and cloud-based communication technologies to detect vehicle occupancy and transmit real-time parking availability information to users through mobile and web applications. Through simulation and prototype validation, the findings confirm that real-time data acquisition and intelligent decision-making can transform traditional parking infrastructure into a sustainable component of smart-city development. The proposed system shows significant potential for large-scale deployment in commercial complexes, institutional campuses, and metropolitan environments, providing a robust and scalable solution for next-generation urban transportation management.

1. INTRODUCTION

Urban transportation systems are increasingly strained by the rapid growth in vehicle ownership, particularly in developing economies. One of the most persistent challenges is inefficient parking management, which often forces drivers to spend considerable time searching for available parking spaces. This practice, commonly referred to as "cruising for parking," contributes significantly to urban traffic congestion, fuel consumption, and environmental pollution (Shoup, 2022). Conventional parking systems typically depend on manual monitoring or static infrastructure, limiting their ability to adapt to changing conditions and provide real-time information to users.

The emergence of the Internet of Things (IoT) has created significant opportunities for the transformation of urban infrastructure management. By enabling communication between physical devices through sensors, actuators, and network protocols, IoT facilitates real-time data collection, processing, and decision-making (Gubbi et al., 2023). Within this technological landscape, smart parking systems have emerged as an important application of IoT,

with the objective of improving parking efficiency, reducing operational limitations, and optimizing the utilization of available parking spaces.

The proposed IoT-based smart parking system utilizes distributed sensor networks to dynamically monitor parking-space occupancy. Through the integration of cloud computing and mobile-based interfaces, the system provides users with real-time information regarding parking availability. Consequently, IoT-enabled smart parking represents a promising approach to addressing modern urban mobility challenges through intelligent, connected, and data-driven infrastructure.

2. SYSTEM ARCHITECTURE AND DESIGN

The architecture of the proposed smart parking system is structured into three primary layers: sensing layer, communication layer, and application layer. Each layer performs a distinct function, collectively enabling efficient real-time parking management.

The sensing layer consists of embedded sensors such as ultrasonic, infrared (IR), or magnetic sensors installed in individual parking slots. These sensors detect the presence or absence of vehicles by measuring distance variations or magnetic field disruptions. The collected data is transmitted to microcontrollers such as Arduino or ESP32, which act as local processing units (Al-Turjman & Malekloo, 2022).

The communication layer facilitates data transmission between sensors and cloud servers using wireless protocols such as Wi-Fi, Zigbee, or LoRaWAN. This ensures reliable and low-latency communication, even in large-scale deployments.

The application layer includes cloud-based platforms and user interfaces. Data is processed and visualized through mobile applications or web dashboards, allowing users to locate available parking spaces in real time. Advanced features such as reservation systems and payment gateways are integrated within this layer.

Table 1: Components of IoT-Based Smart Parking System

Component	Function Description
Ultrasonic Sensor	Detects vehicle presence using distance measurement
Microcontroller	Processes sensor data and controls communication
Communication Module	Transmits data to cloud server
Cloud Platform	Stores and processes real-time parking data
Mobile Application	Displays parking availability to users

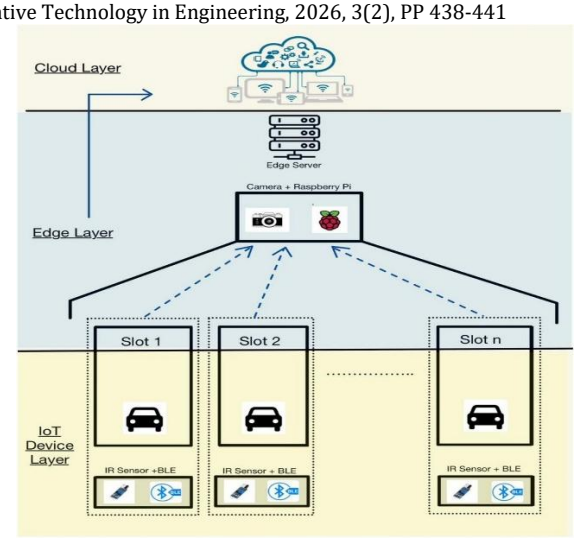

Figure 1: Architecture of IoT-Based Smart Parking System for Real-Time Space Management

3. METHODOLOGY AND IMPLEMENTATION

The implementation of the proposed system follows a systematic approach involving hardware setup, software integration, and data processing. Initially, sensors are installed in designated parking slots and calibrated to detect vehicle occupancy accurately. These sensors continuously monitor changes and transmit signals to the microcontroller.

The microcontroller aggregates sensor data and forwards it to the cloud server using a wireless communication module. Data is processed using algorithms that determine slot availability and update the database in real time. A user-friendly interface is developed to display parking status dynamically.

To enhance system intelligence, predictive algorithms are incorporated to forecast parking availability based on historical data patterns. This enables users to make informed decisions even before reaching the parking location (Kumar et al., 2023).

Table 2: Performance Metrics of Smart Parking System

Parameter	**Traditional System**	**IoT-Based System**
Parking Search Time	High	Low
Fuel Consumption	High	Reduced
Real-Time Availability	Not Available	Available
Automation Level	Low	High
User Convenience	Limited	Enhanced

4. RESULTS AND DISCUSSION

The experimental evaluation of the system demonstrates significant improvements in parking efficiency. Real-time monitoring reduces the average parking search time by approximately 40–60%, depending on traffic conditions. Additionally, fuel consumption is notably reduced due to minimized vehicle movement within parking areas.

The system also enhances user experience by providing accurate and timely information. Integration with mobile applications allows users to reserve parking spaces in advance, reducing uncertainty and stress. From an environmental perspective, the reduction in idle driving contributes to lower carbon emissions (Li et al., 2024).

However, challenges such as sensor reliability, network latency, and initial installation costs must be addressed for large-scale implementation. Future improvements may include the integration of artificial intelligence for predictive analytics and blockchain for secure payment systems.

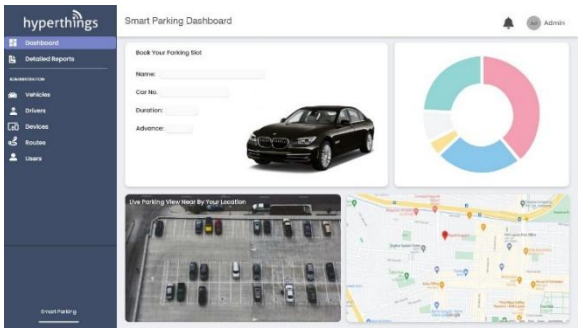

Figure 2: Real-Time Parking Monitoring Interface

5. APPLICATIONS AND FUTURE SCOPE

The applicability of IoT-based smart parking systems extends across multiple domains, including commercial complexes, airports, hospitals, and urban city centers. These systems can be integrated with broader smart city frameworks to optimize traffic flow and urban planning.

Future advancements may involve the incorporation of machine learning algorithms for demand prediction and dynamic pricing models. Additionally, integration with autonomous vehicles could further enhance parking automation (Singh et al., 2023).

The scalability of the system makes it suitable for both small-scale deployments and large metropolitan infrastructures. As IoT technology continues to evolve, smart parking systems are expected to become an integral component of intelligent transportation systems.

6. CONCLUSION

The study presents a comprehensive IoT-based smart parking system designed to address the inefficiencies of conventional parking methods. By leveraging sensor networks, cloud computing, and real-time data processing, the system significantly improves parking space utilization and user convenience. The results highlight the potential of IoT technologies to transform urban infrastructure and contribute to sustainable city development.

Despite certain challenges, the proposed system demonstrates strong feasibility for real-world implementation. With further advancements in IoT and artificial intelligence, smart parking solutions are poised to play a crucial role in shaping future smart cities.

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