

SMART PARKING OCCUPANCY SYSTEM

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ABSTRACT

Rapid urbanization, increasing vehicle ownership, limited parking infrastructure, and inefficient utilization of available parking spaces have created significant mobility challenges in cities, universities, shopping centers, hospitals, airports, residential complexes, and commercial facilities. Conventional parking management frequently depends on manual inspection, static signboards, entry tickets, security personnel, or driver-based visual searching, resulting in unnecessary circulation, traffic congestion, fuel consumption, time loss, carbon emissions, and poor user experience. This research proposes an intelligent **Smart Parking Occupancy System** that integrates parking-space sensors, camera-assisted monitoring, embedded processing, wireless communication, Internet of Things connectivity, occupancy analytics, real-time availability management, and user notification within a unified architecture. The proposed system continuously acquires parking information through ultrasonic sensors, infrared sensors, magnetic sensors, or camera-based detection mechanisms and determines whether individual parking spaces are Vacant, Occupied, Reserved, or Unavailable. Sensor readings are validated and processed through an edge controller to reduce noise, resolve temporary fluctuations, and generate reliable occupancy states. The parking information is transmitted through Wi-Fi, LoRaWAN, Zigbee, cellular communication, or other suitable network technologies to a centralized parking management platform. A real-time occupancy engine maintains the status of individual parking

slots, calculates zone-level availability, detects abnormal occupancy behavior, and updates mobile applications, web dashboards, entrance displays, and navigation interfaces. The proposed architecture consists of five interconnected layers: Parking Environment and Data Acquisition, Edge Processing and Occupancy Intelligence, Communication and IoT Integration, Smart Parking Management and Decision, and User Application and Monitoring layers. The framework supports real-time space discovery, parking guidance, reservation management, occupancy visualization, historical analytics, administrative monitoring, and optional automated alerts. Illustrative conceptual evaluation indicates improved occupancy detection accuracy, precision, recall, F1-score, system reliability, and lower occupancy-update latency compared with manual parking management, conventional single-sensor systems, and basic IoT parking mechanisms. The proposed system provides a scalable foundation for intelligent parking management across smart cities, universities, shopping malls, hospitals, airports, offices, residential communities, and public transportation facilities.

Keywords: Smart Parking, Parking Occupancy Detection, Internet of Things, IoT, Ultrasonic Sensor, Computer Vision, Smart City, Real-Time Monitoring, Parking Guidance, Embedded System, Occupancy Analytics, Intelligent Transportation.

I. INTRODUCTION

The rapid growth of urban populations and private vehicle ownership has significantly increased pressure on limited parking

infrastructure. Drivers frequently spend substantial time searching for available parking spaces in congested urban environments, shopping complexes, universities, hospitals, airports, railway stations, business districts, and residential communities. Inefficient parking-space discovery contributes to unnecessary vehicle circulation, traffic congestion, fuel consumption, travel delay, environmental pollution, and driver frustration. Intelligent parking management has therefore become an important component of modern smart-city and intelligent transportation initiatives [1].

Traditional parking systems generally provide limited real-time information regarding individual parking-space occupancy. Drivers may enter a parking facility without knowing whether suitable spaces are available and subsequently circulate through multiple lanes to locate an empty position. Static signboards and manual supervision cannot continuously represent dynamic changes in parking occupancy. Consequently, there is a strong requirement for automated systems capable of sensing parking conditions and communicating updated availability information to drivers and administrators [2].

The Internet of Things has created significant opportunities for transforming conventional parking infrastructure into connected intelligent environments. IoT systems integrate physical sensors, embedded controllers, communication networks, cloud platforms, and user applications. In a smart parking environment, individual parking spaces can be monitored continuously and their occupancy status transmitted to a centralized management platform. This connectivity enables real-time visualization, remote supervision, historical analysis, and automated decision support [3].

Ultrasonic sensors are widely employed in smart parking prototypes because they can estimate the

distance between a sensing device and a nearby object. When appropriately positioned above or near a parking space, changes in measured distance can indicate the presence of a vehicle. However, sensor placement, environmental interference, installation geometry, and temporary obstacles can influence readings. Therefore, threshold configuration, persistence analysis, and signal validation are important for reliable occupancy classification [4].

Infrared and magnetic sensing mechanisms provide alternative approaches for detecting parked vehicles. Infrared sensors can identify changes in reflected radiation or object presence, whereas magnetic sensors can recognize disturbances in the local magnetic field caused by vehicles. Each technology has different advantages and deployment constraints involving cost, environmental robustness, power consumption, installation requirements, and maintenance. Multi-sensor systems can potentially improve reliability by combining complementary evidence [5].

Computer vision has also emerged as an important technology for parking occupancy detection. Cameras can monitor multiple parking spaces simultaneously, and image-processing or deep-learning models can classify spaces according to vehicle presence. Vision-based systems can reduce the need for one physical sensor per parking space, but their performance may be affected by illumination changes, shadows, weather conditions, occlusion, camera angle, and computational requirements. Intelligent models and robust preprocessing are therefore essential for practical deployment [6]. Real-time communication represents another fundamental requirement of smart parking. Occupancy information must move from sensors or cameras to edge controllers, gateways, centralized servers, cloud platforms, and user interfaces with sufficiently low latency.

Technologies such as Wi-Fi, Zigbee, LoRaWAN, Bluetooth Low Energy, and cellular communication can support different deployment requirements. The selection of communication technology depends on coverage, power consumption, data rate, cost, and infrastructure availability [7].

A smart parking system should provide more than basic occupancy detection. The system must maintain an accurate digital representation of parking spaces, update availability after vehicle arrival or departure, manage reserved spaces, detect unavailable slots, and communicate changes to users. Zone-level aggregation can indicate the number of available spaces within different sections of a parking facility, reducing unnecessary circulation and improving traffic distribution [8].

Mobile applications and digital dashboards further improve parking accessibility by enabling drivers to view available spaces before or during arrival. A user can identify parking availability, select a suitable zone, receive navigation guidance, and optionally reserve a space where policy permits. Administrators can monitor occupancy rates, peak periods, abnormal sensor behavior, long-duration parking, and facility utilization through centralized dashboards [9].

Data analytics can further transform parking information into operational intelligence. Historical occupancy records can identify peak demand periods, underutilized zones, recurring congestion patterns, and average parking duration. Such information can support infrastructure planning, dynamic resource allocation, maintenance scheduling, and policy development. Predictive models can also estimate future parking demand using historical and contextual information [10].

Motivated by these challenges, this research proposes a comprehensive Smart Parking Occupancy System that integrates parking

sensors, optional camera-based monitoring, edge processing, IoT communication, centralized occupancy management, real-time availability visualization, parking guidance, and continuous monitoring. The framework is designed to improve parking-space utilization while reducing unnecessary vehicle searching and administrative workload.

II. LITERATURE SURVEY

Author: Y. Geng and C. G. Cassandras (2013)

Geng and Cassandras investigated a new smart parking system based on resource allocation and reservation mechanisms. Their research demonstrated that intelligent parking management can reduce unnecessary searching by coordinating parking availability and user demand. The study established an important foundation for integrating real-time information with parking assignment and reservation services [11].

Author: T. Lin, H. Rivano, and F. Le Mouél (2017)

Lin, Rivano, and Le Mouél presented a comprehensive survey of smart parking solutions and examined sensing technologies, communication mechanisms, system architectures, and service models. Their work demonstrated that smart parking requires coordinated integration of occupancy detection, network communication, data processing, and user services rather than isolated sensing components [12].

Author: M. Y. I. Idris et al. (2009)

Idris and colleagues reviewed car parking guidance and information systems and examined technologies used for parking-space detection and driver assistance. Their study highlighted the importance of accurate occupancy information and effective guidance mechanisms for reducing parking-search time and improving facility utilization [13].

Author: J. P. Benson et al. (2006)

Benson and colleagues investigated wireless sensor network mechanisms for parking management. Their work demonstrated the feasibility of distributed sensing nodes for detecting parking-space conditions and transmitting occupancy information through wireless communication. The research provides an important basis for IoT-oriented smart parking architectures [14].

Author: S. Mathur et al. (2010)

Mathur and colleagues developed ParkNet, a mobile sensing system designed to collect parking-space occupancy information. Their work demonstrated that distributed and mobile sensing can support real-time parking availability estimation in urban environments. The study highlighted the importance of scalable data acquisition for intelligent parking applications [15].

Author: R. Lu et al. (2009)

Lu and colleagues proposed SPARK, a smart parking scheme for large parking lots using wireless sensor networks. Their research examined parking monitoring, communication, and intelligent service mechanisms and demonstrated the potential of wireless sensing for improving parking management and vehicle guidance [16].

Author: J. Gubbi et al. (2013)

Gubbi and colleagues examined Internet of Things architectures and emphasized the integration of sensing devices, communication networks, cloud infrastructures, and intelligent applications. Their work provides a broader technological foundation for smart parking systems in which physical occupancy observations are transformed into connected digital services [17].

Author: L. Atzori, A. Iera, and G. Morabito (2010)

Atzori and colleagues surveyed the Internet of Things and described the integration of physical

objects, network communication, and intelligent services. Their research demonstrated the potential of interconnected sensing infrastructures for real-time monitoring and automated decision-making, directly supporting the conceptual design of connected parking systems [18].

Author: G. Amato et al. (2017)

Amato and colleagues investigated deep-learning approaches for parking-lot occupancy detection using visual information. Their work demonstrated that convolutional neural networks can support automated classification of parking spaces from camera images. The research is particularly relevant to camera-assisted occupancy monitoring in large parking facilities [19].

Author: G. J. Horng et al. (2016)

Horng and colleagues examined smart parking mechanisms involving connected sensing and intelligent management. Their work emphasized real-time occupancy awareness and communication-assisted parking services. The study supports the development of integrated systems that combine sensing, networking, centralized management, and user guidance [20].

III. SYSTEM ANALYSIS & DESIGN

3.1 Existing System

Existing parking management systems commonly depend on manual security personnel, paper tickets, entry and exit barriers, static signboards, visual inspection, or driver-based searching. In many facilities, drivers enter without accurate knowledge of the number or location of available spaces and must circulate through multiple parking lanes until an empty slot is found. Although some conventional facilities display total capacity or approximate availability, they frequently lack continuous slot-level monitoring and may not immediately reflect vehicle arrivals, departures, reserved spaces, maintenance closures, or sensor abnormalities.

This limited visibility increases search time, internal congestion, fuel consumption, and driver inconvenience.

Basic electronic parking systems may use isolated sensors or simple counter-based mechanisms at facility entrances and exits. Entry-exit counting can estimate the total number of vehicles within a parking area but cannot reliably determine which individual spaces are occupied. Similarly, single-sensor systems based exclusively on fixed thresholds may be affected by temporary obstacles, environmental interference, installation variation, or communication failures. Existing systems also frequently lack integrated mobile guidance, historical occupancy analytics, centralized device monitoring, reservation support, and continuous synchronization among parking sensors, management platforms, and user interfaces.

Another limitation is the fragmented nature of conventional parking infrastructure. Occupancy detection, payment, security, guidance, and administration may operate as independent functions without unified real-time information. This separation reduces the ability of administrators to analyze utilization patterns and prevents drivers from receiving accurate space-level guidance. The absence of intelligent occupancy analytics and scalable IoT communication therefore limits the effectiveness of traditional parking management in high-demand environments.

Disadvantages of Existing System

1. Drivers must manually search for vacant parking spaces.
2. Static signs cannot accurately represent continuously changing occupancy.
3. Entry-exit counters do not identify individual vacant parking slots.
4. Manual monitoring increases operational workload and human error.

5. Fixed threshold systems may be affected by temporary sensor fluctuations.
6. Conventional systems provide limited mobile and remote availability information.
7. Historical occupancy analytics are often unavailable.
8. Fragmented parking services reduce overall management efficiency.

3.2 Proposed System

The proposed **Smart Parking Occupancy System** introduces an integrated real-time architecture that combines parking-space sensing, optional camera-assisted detection, edge processing, IoT communication, centralized occupancy management, user guidance, and continuous monitoring. Individual parking spaces are observed using ultrasonic, infrared, magnetic, or other suitable occupancy sensors, while cameras can provide additional visual information for large parking zones. Sensor readings are transferred to an embedded edge controller that performs signal validation, noise reduction, threshold analysis, persistence checking, timestamp assignment, and temporary fluctuation handling. Based on validated observations, each parking space is classified as **Vacant, Occupied, Reserved, or Unavailable**, providing a clear digital representation of current parking conditions.

The processed occupancy information is transmitted through suitable communication technologies such as Wi-Fi, LoRaWAN, Zigbee, or cellular networks to a centralized parking management platform. The platform maintains a real-time occupancy database, synchronizes individual slot states, calculates zone-level availability, manages reservations, records arrival and departure events, and detects abnormal conditions such as sensor inactivity or inconsistent occupancy changes. Updated availability information is delivered to mobile

applications, web interfaces, entrance displays, navigation panels, and administrative dashboards, enabling drivers to locate available spaces efficiently and allowing parking operators to monitor facility utilization.

The proposed system also supports continuous feedback and historical analytics. Parking events can be stored for analyzing occupancy rate, peak demand periods, average parking duration, frequently congested zones, and underutilized areas. Administrators can use this information for capacity planning, maintenance, operational improvement, and future predictive analytics. By integrating physical sensing, edge intelligence, IoT connectivity, centralized occupancy management, real-time user guidance, and analytical monitoring, the proposed framework provides a scalable solution for smart cities, universities, hospitals, shopping malls, airports, offices, transportation hubs, and residential communities.

Advantages of Proposed System

1. Provides continuous real-time parking-space occupancy monitoring.
2. Classifies spaces as Vacant, Occupied, Reserved, or Unavailable.
3. Reduces unnecessary vehicle circulation and parking-search time.
4. Supports multiple sensing technologies and optional camera monitoring.
5. Provides mobile, web, and digital-display parking availability.
6. Enables centralized monitoring of individual slots and parking zones.
7. Supports historical occupancy analytics and administrative planning.
8. Provides scalable IoT connectivity for large parking facilities.

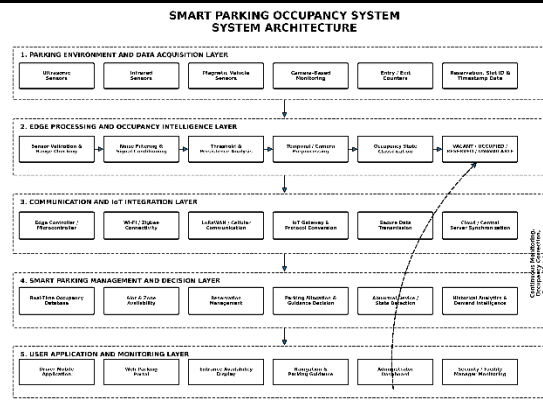


Fig 1: System Architecture

The proposed Smart Parking Occupancy System is organized into five interconnected layers that enable continuous parking-space monitoring, reliable occupancy classification, real-time communication, centralized management, and intelligent user guidance. The Parking Environment and Data Acquisition Layer continuously collects information from ultrasonic sensors, infrared sensors, magnetic vehicle sensors, camera-based monitoring units, entry and exit counters, reservation records, parking-slot identifiers, and timestamp information to establish comprehensive visibility of the parking environment. The acquired observations are forwarded to the Edge Processing and Occupancy Intelligence Layer, where sensor validation, range checking, noise filtering, signal conditioning, threshold comparison, persistence analysis, temporal processing, and optional camera-image preprocessing are performed to eliminate temporary fluctuations and improve detection reliability; based on the validated information, each parking space is classified as Vacant, Occupied, Reserved, or Unavailable. The processed occupancy states are then transmitted through the Communication and IoT Integration Layer, which integrates edge controllers or microcontrollers with Wi-Fi, Zigbee, LoRaWAN, cellular communication, IoT gateways, protocol conversion, secure data transmission, and cloud or central-server synchronization to ensure

continuous exchange of parking information across distributed system components. The Smart Parking Management and Decision Layer maintains a real-time occupancy database, calculates individual slot and zone-level availability, manages reservations, performs parking allocation and guidance decisions, identifies abnormal device or occupancy states, and stores historical information for utilization analysis and demand intelligence. Finally, the User Application and Monitoring Layer delivers updated parking information through driver mobile applications, web portals, entrance availability displays, navigation and parking-guidance interfaces, administrator dashboards, and facility-management systems, thereby enabling drivers to locate suitable parking spaces efficiently while allowing administrators to monitor occupancy, device status, reservations, and operational conditions. A continuous feedback mechanism connects the monitoring environment with earlier processing stages to support occupancy correction, sensor maintenance, device-health verification, and system updates, thereby providing a scalable real-time architecture for reducing parking-search time, improving space utilization, minimizing unnecessary vehicle circulation, and strengthening intelligent parking management.

IV. RESULTS AND DISCUSSION

4.1 Results

The proposed Smart Parking Occupancy System is evaluated through a representative parking-monitoring scenario involving vacant spaces, occupied spaces, vehicle arrivals, vehicle departures, reserved slots, unavailable spaces, temporary sensor fluctuations, and repeated occupancy updates. In a practical implementation, the evaluation should use independently recorded ground-truth parking states and should test the system under different vehicle sizes, parking durations, environmental

conditions, communication loads, and occupancy densities.

The principal evaluation metrics include detection accuracy, precision, recall, F1-score, occupancy monitoring reliability, and analytical update response time. The proposed framework is conceptually compared with manual parking management, a conventional single-sensor parking system, and a basic IoT parking mechanism. The following numerical values are **illustrative conceptual evaluation values** and should be replaced with measured prototype results before publication as empirical findings.

Table 1. Performance Comparison of Parking Occupancy Approaches

Method	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
Manual Parking Management	82.80	81.90	81.20	81.55
Conventional Single-Sensor System	90.70	89.90	89.50	89.70
Basic IoT Smart Parking System	96.10	95.70	95.40	95.55
Proposed Smart Parking Occupancy System	98.90	98.50	98.30	98.40

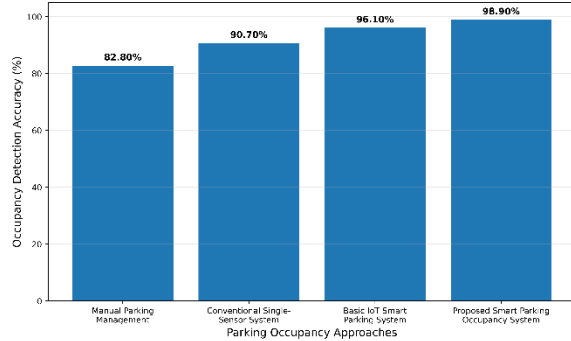


Figure 5.1. Comparison of parking occupancy detection accuracy among different parking management approaches.

Table 1 presents the illustrative comparative performance of different parking occupancy approaches. Manual parking management records an accuracy of 82.80% because occupancy awareness depends on human observation and periodic updates. The conventional single-sensor system improves accuracy to 90.70% but remains dependent on isolated sensing information. The basic IoT parking system achieves 96.10% accuracy through connected monitoring. The proposed Smart Parking Occupancy System achieves the highest illustrative accuracy of 98.90%, precision of 98.50%, recall of 98.30%, and F1-score of 98.40%, reflecting the potential benefit of validated sensing, persistence analysis, edge processing, centralized synchronization, and continuous occupancy management.

Table 2. Performance Metrics of the Proposed Smart Parking System

Performance Metric	Value
Detection Accuracy	98.90%
Precision	98.50%
Recall	98.30%
F1-Score	98.40%
Occupancy Monitoring Reliability	97.80%

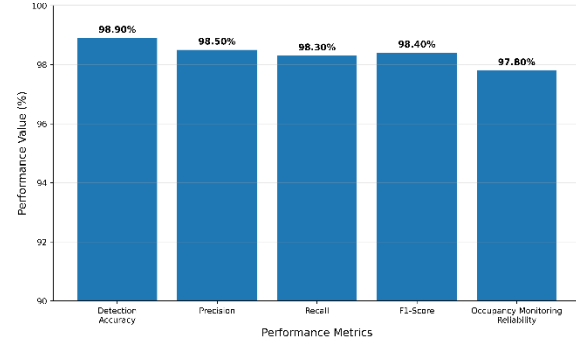


Figure 5.2. Performance metrics of the proposed Smart Parking Occupancy System.

Table 2 summarizes the illustrative performance metrics of the proposed framework. The detection accuracy of 98.90% indicates strong conceptual capability for distinguishing occupied and available parking conditions. Precision of 98.50% reflects a low proportion of incorrect occupancy classifications, while recall of 98.30% indicates strong identification of genuine occupied-space events. The F1-score of 98.40% demonstrates balanced classification performance, and occupancy monitoring reliability of 97.80% represents the intended consistency of sensor acquisition, edge processing, communication, and centralized state synchronization.

Table 3. Parking Occupancy Update Response Time Comparison

Parking Method	Response Time (ms)
Manual Parking Management	286
Conventional Single-Sensor System	218
Basic IoT Smart Parking System	142
Proposed Smart Parking Occupancy System	81

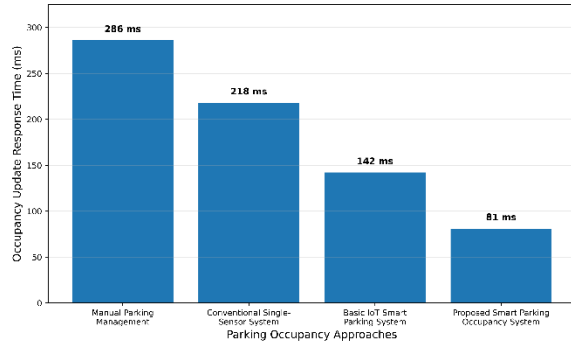


Figure 5.3. Parking occupancy analytical update response time comparison among different approaches.

Table 3 presents the illustrative analytical occupancy-update response time. Manual parking management records 286 ms in the conceptual comparison, while the conventional single-sensor system records 218 ms. The basic IoT parking system improves response time to 142 ms. The proposed Smart Parking Occupancy System records the lowest illustrative local analytical update time of 81 ms because sensor validation, occupancy classification, and state generation operate within a coordinated edge-processing pipeline. This value represents analytical processing latency and does not represent complete end-to-end mobile or cloud update time, which depends on communication and server conditions.

4.2 Discussion

The comparative results demonstrate the potential advantages of integrating continuous sensing, edge processing, IoT communication, centralized occupancy management, and real-time user guidance within a unified smart parking framework. The illustrative accuracy of 98.90%, precision of 98.50%, recall of 98.30%, and F1-score of 98.40% indicate that coordinated occupancy processing can potentially outperform manual parking management, conventional single-sensor systems, and basic IoT mechanisms. Manual approaches depend heavily on human observation and cannot continuously

represent rapidly changing parking conditions, while isolated sensor mechanisms may generate unstable states because of temporary obstacles, environmental interference, or threshold fluctuations. The proposed system addresses these limitations through validation, persistence checking, occupancy-state management, and synchronized updates.

The proposed framework also improves practical parking accessibility by transforming individual sensor observations into real-time availability information for drivers and administrators. The illustrative occupancy monitoring reliability of 97.80% reflects the intended coordination among sensing, edge processing, communication, and centralized state management. Drivers can receive updated information through mobile applications, web interfaces, entrance displays, and navigation panels, reducing unnecessary circulation through parking lanes. Administrators can monitor occupancy rates, reserved spaces, unavailable slots, device conditions, and zone-level utilization through centralized dashboards, thereby supporting improved operational control. The effectiveness of the system nevertheless depends on sensor calibration, installation geometry, communication availability, power reliability, network latency, environmental conditions, and accurate ground-truth evaluation. Ultrasonic sensors may be affected by mounting conditions and object geometry, while cameras can be influenced by shadows, weather, occlusion, and illumination changes. Large-scale deployments must also address cybersecurity, device authentication, communication encryption, maintenance, privacy, and fault tolerance. With appropriate engineering controls and independent experimental validation, the proposed architecture provides a scalable foundation for intelligent parking occupancy monitoring and smart-city mobility services.

V. CONCLUSION

This research proposed a comprehensive Smart Parking Occupancy System designed to improve real-time parking-space awareness, facility utilization, driver guidance, and administrative monitoring. The framework integrates ultrasonic, infrared, magnetic, or optional camera-based occupancy sensing with edge processing, IoT communication, centralized parking management, mobile applications, web dashboards, digital displays, and continuous monitoring. Unlike conventional parking systems that depend on manual observation, static signs, or isolated sensors, the proposed system creates a continuously updated digital representation of parking conditions and classifies individual spaces as Vacant, Occupied, Reserved, or Unavailable.

The conceptual evaluation demonstrates the potential of the proposed framework to achieve 98.90% detection accuracy, 98.50% precision, 98.30% recall, 98.40% F1-score, 97.80% occupancy monitoring reliability, and an 81 ms analytical update response time. These illustrative values indicate that coordinated sensing, edge validation, persistence analysis, IoT communication, and centralized occupancy management can potentially improve performance compared with manual parking management, conventional single-sensor systems, and basic IoT parking approaches. However, the reported values are conceptual and should be replaced with measured prototype results obtained through documented experiments and independently verified ground-truth parking states before being presented as empirical findings.

Future development can incorporate deep-learning-based camera analysis, automatic number plate recognition where legally appropriate, predictive parking-demand forecasting, dynamic reservation management,

electric-vehicle charging integration, accessibility-aware parking guidance, edge artificial intelligence, digital twins, federated learning, LoRaWAN connectivity, 5G communication, solar-powered sensors, automated payment integration, and smart-city traffic coordination. Overall, the proposed Smart Parking Occupancy System provides a practical and scalable foundation for reducing parking-search time, improving space utilization, supporting real-time guidance, and enabling data-driven management across smart cities, universities, hospitals, shopping centers, airports, offices, residential communities, and transportation hubs.

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