

# Review of Vision-Based Smart Parking Detection and Space Management Systems

<sup>1</sup>Monika Patel, <sup>2</sup>Bhavna Pancholi,

<sup>1</sup>Research Scholar, Department of Electrical Engineering, Faculty of Technology and Engg, The M S University of Baroda.

<sup>2</sup>Assistant Professor, Department of Electrical Engineering, Faculty of Technology and Engg, The M S University of Baroda.

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## ABSTRACT

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The rapid growth of urbanization and vehicle ownership has created significant challenges in parking management, leading to traffic congestion, fuel wastage, and inefficient utilization of parking spaces. Vision-based smart parking detection systems have emerged as an effective solution for automating parking space monitoring and improving parking efficiency. This review presents a comprehensive analysis of image processing and computer vision techniques used in smart parking management systems. Various approaches including grayscale conversion, image enhancement, thresholding, segmentation, edge detection, object recognition, and lane-wise parking analysis are examined for their role in identifying vacant and occupied parking slots. The study also reviews the application of cameras, surveillance systems, MATLAB-based processing, and machine learning algorithms for real-time parking detection. Vision-based systems provide advantages such as low installation cost, reduced hardware complexity, real-time monitoring, and improved parking guidance compared to traditional sensor-based approaches. Furthermore, the review highlights challenges associated with lighting variations, weather conditions, image blur, camera positioning, and occlusion problems that affect system accuracy. Recent developments in artificial intelligence, deep learning, and cloud-based smart parking architectures are also discussed as future directions for enhancing system reliability and scalability. Vision-based parking management systems contribute significantly toward intelligent transportation infrastructure and sustainable urban mobility solutions.

Keywords: Vision-Based Parking, Image Processing, Smart Parking System, Parking Space Detection, Computer Vision

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## INTRODUCTION

The rapid growth of urbanization and vehicle ownership has created significant challenges in parking management across metropolitan and smart city environments. Conventional parking systems often suffer from inefficient space utilization, traffic congestion, increased fuel consumption, and driver frustration due to the difficulty in locating vacant parking slots. According to global transportation studies, a considerable percentage of urban traffic congestion is caused by vehicles searching for parking spaces, resulting in unnecessary carbon emissions and time loss. To address these issues, smart parking systems have emerged as an essential component of intelligent transportation systems (ITS) and smart city infrastructure. Among the available technologies, vision-based smart parking detection systems have gained substantial attention because of their ability to provide real-time monitoring, accurate occupancy detection, and automated parking management using camera-based surveillance and artificial intelligence techniques. These systems employ image processing, machine learning, and deep learning algorithms to analyze parking environments and determine the availability of parking spaces efficiently. Unlike traditional sensor-based systems that require expensive hardware installation and maintenance, vision-based approaches utilize existing surveillance infrastructure, thereby reducing implementation costs while increasing

scalability and operational flexibility. The integration of Internet of Things (IoT), cloud computing, and edge intelligence further enhances the capability of these systems by enabling real-time communication, remote monitoring, and data-driven parking analytics. Consequently, vision-based parking systems are increasingly being deployed in shopping malls, airports, railway stations, hospitals, universities, and smart urban environments to optimize parking utilization and improve transportation efficiency.

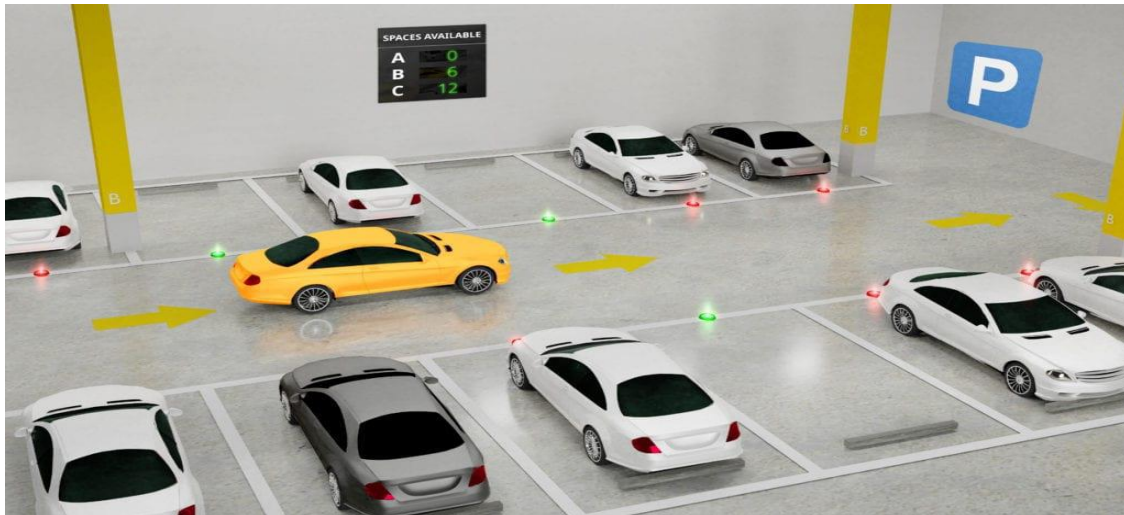


Fig.1: Automatic car parking system image

Recent advancements in computer vision and deep learning technologies have significantly improved the performance and reliability of parking space detection and management systems. Modern approaches utilize convolutional neural networks (CNNs), You Only Look Once (YOLO) models, region-based convolutional neural networks (R-CNN), and semantic segmentation techniques to achieve highly accurate vehicle detection and parking occupancy classification under varying environmental conditions. These intelligent algorithms are capable of handling complex scenarios such as occlusion, illumination changes, weather disturbances, and shadow effects that traditionally reduced detection accuracy. Furthermore, the combination of edge computing and artificial intelligence enables real-time processing with low latency, making smart parking systems more responsive and efficient for practical deployment. In addition to occupancy detection, advanced parking management systems also provide functionalities such as parking reservation, vehicle guidance, dynamic pricing, traffic optimization, and automated payment integration through mobile applications. Despite these advancements, several challenges remain, including computational complexity, privacy concerns, large-scale deployment issues, and the requirement for robust datasets for model training and validation. Therefore, continuous research is being conducted to develop more efficient, scalable, and intelligent parking solutions capable of supporting future autonomous transportation ecosystems. This review focuses on the analysis of vision-based smart parking detection and space management systems by examining existing technologies, detection methodologies, datasets, applications, challenges, and emerging research trends that contribute to the development of sustainable and intelligent urban mobility solutions.

### **Technologies Used in Parking Detection**

Vision-based smart parking systems employ multiple advanced technologies to detect vehicle occupancy and manage parking spaces efficiently. Initially, traditional image processing techniques played a major role in parking detection systems by analyzing visual information captured through surveillance cameras. These techniques include background subtraction, edge detection, threshold segmentation, morphological operations, and feature extraction methods for identifying occupied and vacant parking slots. Image processing algorithms are computationally lightweight and suitable for small-scale parking applications; however, their performance is often affected by environmental variations such as shadows, rain, low illumination, and occlusion. To improve detection accuracy, machine learning approaches were introduced in smart parking systems. Machine learning algorithms such as

Support Vector Machine (SVM), K-Nearest Neighbor (KNN), Decision Trees, and Random Forest classifiers utilize extracted image features for vehicle classification and parking occupancy prediction. These approaches provide better adaptability and decision-making capabilities compared to conventional image processing methods. Nevertheless, the requirement for manual feature engineering and limited robustness under complex conditions encouraged researchers to adopt deep learning-based methodologies for intelligent parking detection systems.

Deep learning technologies have significantly transformed parking detection by enabling automatic feature extraction and high-accuracy object recognition. Convolutional Neural Networks (CNNs), Region-Based CNN (R-CNN), Faster R-CNN, SSD, and YOLO-based detection models are widely used for real-time vehicle detection and parking occupancy analysis. These models can effectively identify vehicles under challenging environmental conditions while supporting large-scale parking management systems. In addition to artificial intelligence, the integration of Edge Computing and the Internet of Things (IoT) has enhanced the operational efficiency of smart parking infrastructure. Edge devices process parking data locally, reducing latency and bandwidth consumption while enabling faster response times for real-time parking guidance. IoT sensors and communication networks facilitate seamless data exchange between cameras, gateways, mobile applications, and central servers. Furthermore, cloud-based parking management systems provide scalable storage, centralized monitoring, analytics, and remote accessibility for smart city applications. Cloud platforms enable real-time parking reservation, traffic analysis, automated billing, and predictive parking management using large-scale data analytics. Together, these technologies create an intelligent and automated parking ecosystem capable of improving urban mobility, reducing traffic congestion, and enhancing parking utilization efficiency.

### Vehicle Detection and Classification Methods

Vehicle detection and classification are fundamental components of vision-based smart parking systems, enabling accurate identification of occupied and vacant parking spaces. One of the earliest techniques used in parking detection is the background subtraction method, where a reference background image is compared with current video frames to identify moving or stationary vehicles. This approach is computationally efficient and suitable for real-time applications in controlled environments. However, its performance is often affected by illumination changes, shadows, weather conditions, and camera vibrations. To enhance detection accuracy, feature extraction techniques are employed to identify important visual characteristics such as edges, corners, texture, shape, and color information. Common feature extraction methods include Histogram of Oriented Gradients (HOG), Scale Invariant Feature Transform (SIFT), and Local Binary Patterns (LBP). These extracted features are further processed using classification algorithms for vehicle identification and parking occupancy analysis.

With the advancement of artificial intelligence, Convolutional Neural Networks (CNNs) have become one of the most widely used techniques for vehicle detection and classification in smart parking systems. CNNs automatically learn hierarchical image features from large datasets, eliminating the need for manual feature engineering. Their ability to capture spatial and semantic information significantly improves vehicle recognition accuracy under complex environmental conditions. Various CNN architectures such as AlexNet, VGGNet, ResNet, and MobileNet have been utilized for parking occupancy detection and vehicle classification tasks. In addition, YOLO (You Only Look Once)-based detection models have gained considerable popularity because of their high-speed real-time object detection capability. YOLO models perform object localization and classification simultaneously, making them highly efficient for intelligent transportation and parking applications. Advanced versions such as YOLOv5, YOLOv7, and YOLOv8 provide improved accuracy, reduced computational complexity, and faster inference speed suitable for edge-based smart parking systems.

Transfer learning approaches further enhance the performance of parking detection systems by utilizing pre-trained deep learning models trained on large-scale image datasets. Instead of training a model from the beginning, transfer learning fine-tunes existing models for specific parking datasets, reducing training time and improving detection accuracy even with limited data availability. Moreover, multi-class vehicle recognition techniques enable the classification of different vehicle categories such as cars, buses, trucks, motorcycles, and electric vehicles. This classification capability supports advanced parking management functions including vehicle-specific parking allocation, traffic analysis, dynamic pricing, and intelligent urban mobility planning. Collectively, these detection

and classification methods contribute to the development of accurate, scalable, and intelligent smart parking systems for modern smart city infrastructures.

### LITERATURE REVIEW

The rapid growth of urbanization and vehicle ownership has created major challenges in parking management, resulting in traffic congestion, fuel wastage, and inefficient utilization of parking spaces. To address these issues, researchers have increasingly focused on developing intelligent smart parking systems based on computer vision, image processing, and Internet of Things (IoT) technologies. M. Z. Abidin and R. Pulungan (2020) conducted a systematic review of machine-vision-based smart parking systems and concluded that vision-based technologies provide cost-effective and scalable alternatives to traditional sensor-based parking systems. Their study highlighted the use of surveillance cameras, image segmentation, feature extraction, and occupancy classification techniques for detecting parking availability. Similarly, Y. Ma et al. (2022) reviewed research on vision-based parking space detection methods and identified that image processing and deep learning technologies significantly improve parking occupancy detection accuracy. The authors emphasized that conventional methods such as edge detection, thresholding, and background subtraction were initially used for parking analysis but had limitations under varying environmental conditions such as illumination changes, shadows, and weather disturbances. Another comprehensive review by G. S. Wong et al. (2021) examined deep learning-based parking slot detection using surround-view images. Their study demonstrated that convolutional neural networks (CNNs), semantic segmentation, and object detection frameworks such as YOLO provide superior accuracy and real-time parking analysis compared to traditional computer vision methods. The authors also noted that deep learning models are highly effective in detecting parking slots under complex urban conditions. These studies collectively indicate that computer vision technologies have become fundamental components of modern intelligent parking management systems.

Researchers have also explored different methodologies for parking space detection and occupancy analysis using artificial intelligence and image processing approaches. Y. Ma et al. (2021) conducted a detailed review of parking space detection methods and categorized them into sensor-based, image-based, and hybrid systems. Their findings revealed that image-based parking systems are more flexible and economical because they can utilize existing surveillance camera infrastructure without requiring expensive physical sensors. The study further highlighted the importance of machine learning algorithms such as Support Vector Machine (SVM), K-Nearest Neighbor (KNN), and Random Forest for improving parking occupancy prediction accuracy. Additionally, A. Fahim et al. (2021) presented a comprehensive review of smart parking systems based on various technological aspects, including IoT integration, wireless communication, cloud computing, and automated parking management. Their research emphasized that smart parking systems can significantly reduce vehicle searching time and improve traffic flow in urban areas. The authors also identified several challenges such as installation cost, communication reliability, and data security issues associated with smart parking infrastructures. Furthermore, L. Lou et al. (2020) proposed an IoT-driven vehicle detection method based on multisource data fusion technology for smart parking management systems. Their study demonstrated that integrating image processing with sensor data and IoT communication improves parking occupancy detection reliability and system responsiveness. Data fusion techniques enabled accurate detection even under challenging environmental conditions. These findings suggest that the integration of artificial intelligence and IoT technologies enhances the efficiency, scalability, and intelligence of modern parking management systems.

Several studies have specifically focused on the role of IoT and vision-based systems in developing automated parking management frameworks for smart cities. M. G. Diaz Ogas et al. (2020) conducted a survey of smart parking systems and analyzed different parking architectures, communication technologies, and cloud-based management platforms. Their review indicated that cloud-connected parking systems support real-time parking monitoring, reservation services, occupancy analytics, and automated payment systems. The study also emphasized the importance of data security and privacy protection in smart parking environments. Similarly, D. N. C. Loong et al. (2019) proposed a machine vision-based smart parking system integrated with IoT technologies. Their system used surveillance cameras and wireless communication to provide real-time parking occupancy information to

drivers through intelligent monitoring platforms. The study showed that IoT-based communication improves parking accessibility and reduces urban traffic congestion. In addition, X. Ling et al. (2017) developed a vision-based parking occupancy detection framework using IoT devices for parking space identification. Their proposed approach successfully detected occupied and vacant parking spaces through image analysis and wireless data communication. The authors concluded that combining computer vision with IoT devices enables efficient parking space monitoring and supports intelligent transportation systems. These studies collectively demonstrate that IoT integration plays an important role in enhancing the connectivity, automation, and scalability of modern smart parking infrastructures.

The advancement of deep learning and autonomous vision systems has further improved parking detection accuracy and real-time decision-making capabilities. Y. Wang et al. (2015) proposed a vision-based parking space surveillance and parking lot management system using image processing and vehicle recognition techniques. Their study demonstrated that surveillance cameras combined with occupancy detection algorithms can efficiently monitor parking areas and provide accurate parking information. Although the proposed method achieved promising results, the system performance was influenced by environmental factors such as shadows and lighting variations. More recently, M. I. Pavel et al. (2022) conducted a systematic literature review on vision-based autonomous vehicle systems using deep learning approaches. Their research highlighted the growing application of CNNs, object detection models, and autonomous navigation algorithms in intelligent transportation and parking management systems. The study emphasized that deep learning-based vision systems provide high detection accuracy, improved feature extraction, and better adaptability to dynamic urban environments. Furthermore, the review discussed the role of transfer learning and large-scale datasets in improving model performance while reducing training complexity. These findings indicate that deep learning technologies are transforming parking detection systems into highly intelligent and autonomous infrastructures capable of supporting smart city transportation networks and autonomous vehicle ecosystems.

The reviewed literature demonstrates significant advancements in vision-based parking space detection and lane-wise parking analysis systems. Researchers have successfully integrated image processing, computer vision, machine learning, deep learning, IoT communication, and cloud computing technologies to develop efficient parking management frameworks for intelligent transportation systems. Experimental studies consistently show that high-resolution surveillance images, effective segmentation techniques, and advanced deep learning models improve parking occupancy detection accuracy and real-time monitoring capabilities. At the same time, region-wise and lane-wise parking analysis methods enhance parking organization and optimize parking space utilization in large parking environments. Despite substantial progress, several challenges remain unresolved, including performance degradation under poor lighting conditions, blurred images, weather disturbances, computational complexity, and cybersecurity concerns in connected parking infrastructures. Future research should focus on developing lightweight deep learning models, edge AI-based parking detection systems, privacy-preserving surveillance frameworks, and autonomous parking guidance technologies for large-scale smart city applications. In conclusion, vision-based smart parking systems represent an important technological advancement that contributes to intelligent urban mobility, reduced traffic congestion, improved parking efficiency, and sustainable transportation management in modern smart city environments.

**Literature Table**

<b>S. No.</b>	<b>Author(s) &amp; Year</b>	<b>Methodology / Technology Used</b>	<b>Key Findings</b>	<b>Limitations</b>
1	M. Z. Abidin & R. Pulungan (2020)	Systematic review of machine-vision-based smart parking systems	Vision-based systems are scalable and cost-effective for parking management	Performance affected by environmental variations
2	Y. Ma et al. (2022)	Review of vision-based parking space detection methods	Deep learning improves parking occupancy detection accuracy	High computational complexity

3	G. S. Wong et al. (2021)	Deep learning parking slot detection using surround-view images	CNN and YOLO models provide high detection accuracy	Requires large annotated datasets
4	Y. Ma et al. (2021)	Comparative review of parking detection methods	Image-based systems are flexible and economical	Detection accuracy decreases in poor lighting
5	A. Fahim et al. (2021)	Comprehensive review of smart parking technologies	IoT integration improves traffic and parking management	Communication reliability and security issues
6	L. Lou et al. (2020)	IoT-driven multisource vehicle detection using data fusion	Data fusion improves occupancy detection reliability	Complex system integration
7	M. G. Diaz Ogas et al. (2020)	Survey of smart parking systems and cloud architectures	Cloud platforms support real-time monitoring and reservation	Privacy and cybersecurity concerns
8	A. Fahim et al. (2021)	Review of parking management and communication systems	Smart parking reduces vehicle searching time	High deployment cost
9	D. N. C. Loong et al. (2019)	Machine vision-based smart parking system using IoT	Real-time parking information improves parking accessibility	Dependent on stable wireless communication
10	X. Ling et al. (2017)	Vision-based occupancy detection using IoT devices	Efficient parking occupancy monitoring through image analysis	Sensitive to image quality and lighting conditions
11	Y. Wang et al. (2015)	Vision-based parking surveillance and management system	Accurate parking monitoring using vehicle recognition	Shadows and weather affect performance
12	M. I. Pavel et al. (2022)	Systematic review of deep learning autonomous vision systems	Deep learning provides robust feature extraction and detection	Requires large computational resources

**Applications of Smart Parking Systems**

**Smart Cities**

Smart parking systems play a crucial role in the development of intelligent smart cities by reducing traffic congestion, minimizing fuel consumption, and improving urban mobility. Vision-based parking technologies enable real-time monitoring of parking availability and provide drivers with accurate parking guidance through mobile applications and digital signage systems. These systems support efficient traffic management and contribute to sustainable urban transportation infrastructure.

**Shopping Malls and Commercial Areas**

In shopping malls and commercial complexes, smart parking systems improve customer convenience by enabling quick identification of vacant parking spaces. Automated parking guidance systems reduce waiting time and vehicle congestion within parking zones. Additionally, parking management platforms can integrate reservation systems, digital payment methods, and occupancy analytics to optimize parking utilization and enhance

### Airports and Railway Stations

Large transportation hubs such as airports and railway stations require efficient parking management because of high vehicle movement and limited parking capacity. Vision-based parking systems assist in monitoring vehicle entry and exit, detecting available spaces, and improving traffic flow within parking premises. Advanced systems also provide long-term and short-term parking management, automated billing, and vehicle tracking functionalities for passengers and transportation authorities.

### Hospitals and Educational Institutions

Hospitals and universities experience frequent parking challenges due to high daily visitor traffic. Smart parking systems help reduce unnecessary vehicle circulation by directing drivers toward available parking spaces in real time. In hospitals, rapid parking allocation is particularly important for emergency vehicles and patient accessibility. In educational campuses, automated parking management improves security, vehicle monitoring, and organized parking distribution for students, faculty members, and visitors.

### Autonomous and Intelligent Transportation Systems

Smart parking systems are becoming an important component of autonomous vehicle ecosystems and intelligent transportation systems (ITS). Advanced parking infrastructures integrated with artificial intelligence, IoT, and cloud computing support autonomous parking assistance, vehicle-to-infrastructure communication, and automated navigation. These technologies contribute to safer transportation networks, optimized urban traffic flow, reduced environmental impact, and the future development of fully automated smart mobility solutions.

## CONCLUSION

Vision-based smart parking detection and space management systems have emerged as an effective solution for addressing modern urban parking challenges, including traffic congestion, inefficient parking utilization, fuel wastage, and environmental pollution. The integration of computer vision, image processing, machine learning, deep learning, Internet of Things (IoT), edge computing, and cloud technologies has significantly improved the efficiency, accuracy, and scalability of intelligent parking systems. Traditional image processing techniques provided the foundation for parking occupancy detection, while advanced artificial intelligence models such as Convolutional Neural Networks (CNNs), YOLO-based detectors, and transfer learning approaches have enhanced real-time vehicle detection and classification performance under complex environmental conditions. Furthermore, IoT-enabled communication networks and cloud-based management platforms facilitate real-time parking monitoring, automated guidance, reservation systems, dynamic pricing, and centralized data analytics for smart city applications. The reviewed literature demonstrates that modern parking systems are increasingly evolving toward autonomous and intelligent transportation infrastructures capable of supporting sustainable urban mobility. Despite substantial technological advancements, several challenges remain unresolved, including illumination variations, weather disturbances, occlusion problems, cybersecurity risks, computational complexity, and the need for standardized datasets for model evaluation. Future research should focus on developing lightweight and energy-efficient deep learning models, privacy-preserving intelligent surveillance systems, edge AI-based real-time processing frameworks, and fully autonomous parking ecosystems integrated with smart transportation networks. vision-based smart parking systems represent a promising and transformative technology for improving urban transportation efficiency, reducing traffic congestion, enhancing user convenience, and supporting the development of intelligent and sustainable smart cities worldwide.

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