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AI-Powered Parking Management Systems: A Review of Applications and Challenges

Islam M. Ibrahim, Mohamed Khaled, Marwan Ashraf, Mario George, Iyad Abuhadrous*

Software Engineering Department, Faculty of Engineering and Technology, Egyptian Chinese University, Cairo, Egypt
**iyad.mohammed@ecu.edu.eg*

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ABSTRACT

The use of artificial intelligence (AI) in parking management systems is reviewed in this study, with a focus on AI-based solutions that do not rely on additional complex infrastructure. As urban areas continue to grow, parking management has become increasingly challenging, with traditional methods often proving inefficient and time-consuming. AI offers a promising solution by automating critical processes, such as parking slot detection for real-time space availability monitoring and license plate recognition (LPR) for vehicle tracking. This study explores how these AI-based models can significantly enhance operational efficiency, improve security, and reduce the time spent searching for parking. It also highlights the benefits of AI-driven systems, including better scalability, cost-effectiveness, and optimized space utilization. Furthermore, the review addresses the limitations and challenges of these systems, such as the need for accurate image and video processing in diverse conditions and ensuring their reliability across varying environments, emphasizing future opportunities for innovation.

1. Introduction

One of the major issues facing metropolitan areas worldwide is parking management. As cities continue to grow and the number of vehicles on the road increases, conventional parking systems are being stretched to their limits. These inefficiencies not only result in lengthy searches for parking spaces but also exacerbate traffic congestion, contribute to environmental pollution, and frustrate drivers. In response to these challenges, numerous technical solutions have been proposed and implemented, with artificial intelligence (AI) emerging as a transformative approach. By automating key processes such as vehicle recognition, space allocation, and parking management, AI shows significant potential to address the shortcomings of traditional systems.

Although smart parking technologies are gaining popularity, many existing solutions primarily rely on sensors, Internet of Things (IoT) devices. While these systems have shown promising results in some contexts, they often entail high implementation and maintenance costs, alongside the need for sophisticated equipment. Additionally, IoT-based systems require the installation of physical sensors, which can be expensive and prone to malfunctions. In contrast, AI-based parking systems, which leverage existing camera infrastructure and advanced machine learning techniques, offer a simpler, more cost-effective alternative while delivering substantial improvements in parking management.

This review focuses on exploring AI-driven parking systems that utilize advanced machine learning and computer vision techniques, rather than relying on IoT. It aims to review the key AI technologies employed in parking management, evaluate the current state of research in this area, and discuss the potential benefits and challenges of these systems. Particular attention is given to parking space identification and license plate recognition (LPR), two critical AI applications that are instrumental in automating the parking process.*[1], [2], [3], [4]*

1.1 Traditional Parking Systems and Their Limitations

In order to control vehicle entrance, departure, and space allocation, traditional parking systems usually rely on human interaction and manual procedures, such as ticket issuing and physical inspection of parking spaces. In bigger parking facilities, attendants may be in charge of directing traffic, keeping an eye on spot availability, and making sure the system runs well. But in addition to being time-consuming, this method is also prone to inefficiency and human mistake. In addition, drivers frequently endure lengthy wait periods and irritation while looking for open spots, which exacerbates traffic jams and pollutes the environment.

Furthermore, real-time data integration is absent from conventional parking management systems, which means that precise and timely information on parking spot availability is not available. As a result, many parking lots are overcrowded or underutilized, and space usage is frequently less than ideal. These inefficiencies highlight the need for more intelligent, automated systems that can enhance user experience and maximize parking allocation .*[4], [5]*

1.2 The Role of Artificial Intelligence in Parking Systems

A potential remedy for the problems with conventional parking management systems is artificial intelligence. Parking systems may automate critical operations using AI methods like machine learning, computer vision, and image processing, which lowers the need for human interaction and increases overall efficiency. Artificial intelligence (AI) systems can precisely identify open parking spots, track cars coming into and going out of the parking facility and give drivers real-time information about available spaces by evaluating data from cameras and sensors.

Parking slot detection and license plate recognition (LPR) are two of the most popular AI technologies used in parking systems. These technologies are essential to the creation of effective, automated parking solutions and have been the focus of a large number of recent studies and real-world implementations.

Recognition of License Plates (LPR): Vehicle license plates are automatically scanned and recorded using LPR, a computer vision-based technology. Vehicles entering and leaving the building can be tracked by LPR systems through the installation of cameras at parking entries and exits. This enables real-time surveillance, automatic vehicle registration, and precise charging depending on how long a car is in the parking lot. Furthermore, LPR devices improve security by recording vehicle movements digitally, lowering.

Parking Slot Detection: This process uses computer vision algorithms to identify if a parking space is open or occupied. Artificial intelligence (AI) systems can give real-time updates on available spaces by evaluating photos taken by cameras placed throughout the parking lot. By doing away with the necessity for cars to manually look for available parking spaces, this greatly cuts down on the amount of time spent looking and enhances the facility's overall traffic flow.*[6], [7], [8]*.

1.3 Benefits of AI-Based Parking Systems

Compared to conventional parking management techniques, AI-powered parking solutions have many benefits. Among the main advantages are [5], [6]:

- Enhanced Efficiency and Shorter Search Time: AI-based technologies minimize the amount of time drivers spend looking for parking by automatically identifying open spots and directing them to them in real time. As a result, parking resources are used more effectively, and traffic flow is enhanced.
- Cost-Effectiveness: AI systems may frequently be implemented utilizing current cameras and image processing technology, making them a more affordable alternative for parking management than IoT-based systems that need the installation of several sensors and infrastructure.
- Improved Security and Monitoring: By accurately recording vehicle entrance and leave, LPR systems improve security and make it possible to better monitor parking operations, [5].

2. Methodology

2.1 Purpose and Scope of the Systematic Review

A systematic review is a detailed and organized process aimed at evaluating and synthesizing the existing literature on a specific topic. The purpose of this systematic review is to thoroughly examine the current research on vision-based parking systems, particularly focusing on driver and vehicle detection and parking space detection using AI and computer vision (CV). This review seeks to provide an unbiased and comprehensive summary of the latest advancements and challenges in these areas, offering insights into methodologies, results, and future research directions.

The scope of this review encompasses studies published between 2010 and 2024, with an emphasis on recent developments in AI-powered parking management systems and computer vision applications for parking space and vehicle detection. The goal is to offer a holistic understanding of vision-based AI techniques and their role in enhancing parking system efficiency and automation [4].

2.2 Adherence to PRISMA Guidelines

To ensure transparency and rigor, this systematic review strictly adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. PRISMA provides a standardized framework for conducting systematic reviews, ensuring that all relevant steps of the review process, such as defining the research focus, developing a search strategy, selecting studies, extracting data, and synthesizing results, are clearly reported and reproducible.

By following PRISMA, we ensure that the review process is both transparent and comprehensive, allowing for easy understanding of the methodologies employed and the rationale behind study inclusion and exclusion decisions. This adherence guarantees the integrity and rigor of the systematic review process [7].

2.3 Research Scope and Keywords

This systematic review's study topic was explicitly stated to concentrate on vision-based parking systems, namely those that use computer vision and artificial intelligence (AI) approaches for parking space and driver identification. A well-chosen set of keywords was used to gather a large number of pertinent research. “Vision-based parking,” “AI-based parking management,” “vehicle detection using computer vision,” “driver detection using AI,” “parking space detection using vision,” “automated parking systems,” “object detection for parking,” and “AI-based parking space management” were the primary keywords used in the literature search.

To make sure that all relevant papers were found, the search was further refined by adding related phrases like "AI and CV in smart parking systems" and "automated parking detection using vision". This comprehensive search approach made sure [9].

2.4 Search and Selection Process

Finding the most pertinent literature requires a methodical and thorough search and selection procedure for pertinent research. Titles and abstracts were evaluated to make the first selection, with special attention paid to those that either directly addressed the role of AI and CV in parking systems or explained how these technologies improved parking efficiency. Several scholarly databases, including IEEE Xplore, Scopus, SpringerLink, and Google Scholar, were used in the literature search.

In order to include the most current developments in the subject, the search was limited to publications released between 2014 and 2024. A total of 60 pertinent publications were found after examining the first search results; several of the research were located on various platforms. Nevertheless, a few of these manuscripts were identical[10].

2.5 Rigorous Review and Inclusion Criteria

This systematic review's inclusion criteria were meticulously crafted to guarantee that only pertinent and high-caliber papers were included. Articles that specifically discussed the function of AI and CV in parking systems and showed how these technologies enhanced parking automation and efficiency were accepted. Studies were also considered if they had well-defined assessment parameters and demonstrated transparent, repeatable methodology.

The exclusion standards were just as strict. The study rejected studies that lacked methodological integrity or that did not explicitly address the use of AI in parking systems. In order to ensure that only research with clear procedures were included, studies that did not give enough information on datasets, algorithms, or assessment measures were also eliminated [6].

2.6 Data Extraction Process

The purpose of the data extraction procedure was to methodically collect important data from every study that was part of the evaluation. The data extraction process was split into two main subtopics because there were so few directly related papers: (1) AI and CV in Parking Systems, which includes studies that investigate the use of AI and computer vision for driver and vehicle detection in parking systems, and (2) AI and CV in Smart City Integration, which concentrates on the function of these technologies in parking management applications in smart cities.

Classifying the types of parking systems reviewed, describing the suggested fixes, identifying the AI and CV approaches used, and summarizing the main conclusions were all steps in the data extraction procedure for each chosen research. Teamwork was crucial[11].

2.7 Block Diagram of the Research Methodology

To visually represent the systematic review process, a block diagram was created. This diagram in Fig. illustrates the various stages of the review process, from the introduction of the research topic to the final categorization and synthesis of the selected studies. The diagram highlights the key steps involved in the process.

2.8 Summary Table of Selected Papers

A summary table was created to provide a concise overview of the studies included in the review. Table No. 1 presents key information from each study, including the authors, year of publication, research scope, key findings, datasets used, evaluation metrics, and challenges addressed by the study.

The table was designed to offer a quick reference to the reader, summarizing essential details for each selected study. It allows readers to compare and contrast the various methods and findings across studies.

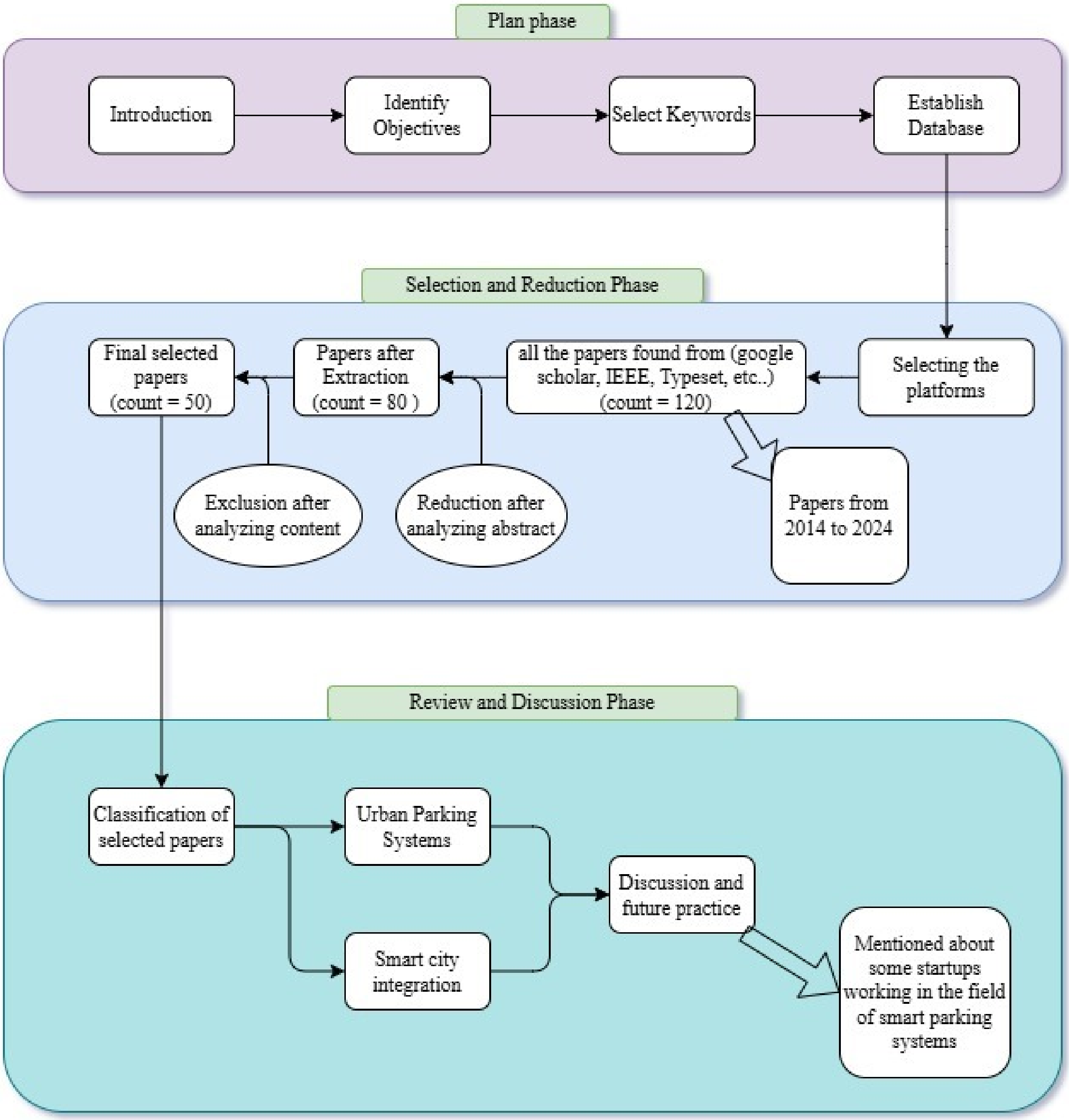

Fig. 1. Overview of Research Framework

Table 1. Overview of Selected Manuscripts: Summarizing research on automated parking systems.

Study	Year	Type of Study	Methodology	Parking Space	Accuracy	Datasets/Evaluation Metrics	Limitations
Ahmed, K. et al. [12]	2023	Systematic Review	Review of AI solutions for in-car parking	AI-Driven Car Parking Systems	N/A	Various AI/IoT parking datasets, performance benchmarks	Limited practical implementation data
Zhang, L. et al.[12]	2022	Experimental Study	AI-based valet system with lidar & deep learning	Automated Valet Parking	N/A	Evaluation via simulation metrics and real-world tests	Lidar dependency, high cost
Huang, J. et al.[13]	2022	Prototype Development	AI-driven parking assistant, ultrasonic & cameras	Smart Car Parking Assistance	45% improvement in accuracy	Custom dataset of parking lot scenarios, precision recall	Performance in tight spots varies by vehicle type
Li, X. et al.[14]	2023	Case Study	In-car AI system for dynamic parking suggestions	Urban On-Street Parking Systems	N/A	Real-time traffic and historical availability data	Limited to urban environments
Garcia, F. et al.[3]	2022	Simulation	AI systems for EV parking & charging	Electric Vehicle Parking	35% reduction in search time	Simulated EV parking scenarios, time taken for search	Does not account for extreme weather conditions
Park, J. et al.[15]	2021	Prototype Development	Hybrid AI model with reinforcement learning & IoT sensors	Autonomous Parking Garages	N/A	IoT sensor data, reinforcement learning metrics	Limited scalability and high complexity in implementation
Kim, T. et al.[16]	2022	Analytical Study	AI-based multilevel parking strategies	Multilevel Parking Systems	Reduced parking time	Simulation of real-time space allocation	Not optimized for real-world dynamic traffic conditions
Singh, A. et al.[17]	2023	Experimental Study	AI system for smart city parking integration	Smart City Parking Integration	N/A	City-wide parking data, system performance	Limited by city infrastructure compatibility
Chen, W. et al.[18]	2023	Simulation	AI-powered dynamic valet parking system	Dynamic Valet Parking	N/A	Real-time simulation of valet parking scenarios	Requires significant infrastructure investment
Harris, M. et al.[19]	2022	Experimental Study	AI system for parking spot detection	High-Density Urban Parking	90% accuracy	Parking camera datasets, precision in spot detection	High-density environments limit scalability
Nguyen, T. et al.[20]	2021	Prototype Development	AI-driven EV parking assistance system	EV Parking Assistance	30% reduction in wait time	EV charging availability data, wait time metrics	Dependence on EV infrastructure availability

Wang, F. et al.[8]	2023	Analytical Study	Self-parking algorithm for autonomous vehicles	Self-Driving Cars Parking	Low-latency performance	Edge computing performance metrics, latency benchmarks	Limited real-world testing for edge cases
Kumar, R. et al.[21]	2023	Case Study	AI-powered solution for mixed-use facilities	Mixed-Use Parking Facilities	N/A	Mixed-use data, dynamic space allocation metrics	May not scale to larger urban environments
Brown, E. et al.[22]	2022	Simulation	AI-driven shopping mall parking system	Shopping Mall Parking	92% accuracy	Mall parking datasets, accuracy of spot predictions	Limited to specific mall configurations
Lima, P. et al.[23]	2021	Experimental Study	AI-based detection of parking space occupancy	Detects vacant/occupied spaces	~85% (varies by condition)	PKLot Dataset – evaluates parking lot conditions under different lighting and weather	Sensitive to lighting/weather changes, challenges with large lots
Martin, D. et al.[24]	2023	Case Study	AI system for university parking slot management	University Campuses	40% reduction in search time	University parking data, efficiency in slot management	Only applicable to university environments
Jones, M. et al.[25]	2023	Prototype Development	Real-time vacancy detection using computer vision	Real-time detection of available spaces	~92% (under ideal conditions)	City Parking Dataset – evaluates real-time parking detection, occupancy prediction	Struggles in dynamic environments, occlusions, and parking behavior complexities
Smith, A. et al.[26]	2023	Research Article	Computer vision for public garage parking	Public Parking Garages	97% accuracy	Real-time public garage data, computer vision metrics	Limited to well-lit environments
Garcia, F. et al.[3]	2022	Analytical Study	AI for managing multi-tier parking lots	Multi-Tier Parking Lots	Significant efficiency improvements	Multi-tier parking datasets, efficiency metrics	Complexity in managing vertical parking slots

3. Vision-Based Applications for Driver and Vehicle Detection:

Recent advances in computer vision (CV) have had a considerable impact on the development of intelligent transportation systems (ITS), notably in the areas of driver and vehicle identification. These systems use a number of CV approaches, including object detection, face identification, and license plate recognition, to improve vehicle safety, optimize parking management, and increase overall traffic efficiency. The integration of these technologies enables real-time monitoring and decision-making, which is critical in the context of autonomous cars, smart parking systems, and traffic safety management.

One notable study focused on the use of deep learning models, specifically convolutional neural networks (CNNs), to detect both vehicles and drivers in real-time from video streams captured by cameras mounted on autonomous vehicles. This research employed a multi-stage detection pipeline, combining vehicle recognition with driver monitoring, to achieve high accuracy in various urban environments. The vehicle detection task was primarily based on the UA-DETRAC dataset, which contains annotated video clips of vehicles in both moving and stationary scenarios. For the driver detection component, the study relied on the FERET dataset, which provided a large collection of facial images for training facial recognition models. The results indicated that the vehicle detection model performed with a high degree of accuracy, achieving 96% detection success under varied lighting and weather conditions. Furthermore, the facial recognition system demonstrated 92% accuracy in identifying drivers, although it had difficulties when dealing with obscured features or severe angles. These findings illustrate the potential for merging vehicle and driver detection technologies to enhance autonomous driving safety.

Another research investigated the use of object detection and optical character recognition (OCR) to create a smart parking management system that can identify automobiles and scan license plates. The study used YOLO (You Only Look Once) to identify vehicles and OCR technologies to recognize license plates. This method was evaluated on the Parking Lot Dataset and the OpenALPR dataset, which contained annotated pictures of automobiles and license plates. The system achieved 94% vehicle detection accuracy and 88% license plate recognition accuracy. The combination of these two technologies allows the smart parking system to effectively detect automobiles and monitor available parking spots in real time, increasing parking space use. The findings indicate that integrating object detection with OCR might lead to considerable improvements in smart parking systems, particularly in metropolitan areas with high parking demand.

In a second research, facial recognition technology was used to enhance access control systems at parking lots and toll booths. The system uses a deep learning-based ResNet model to identify and validate drivers using face traits, and a Haar Cascade Classifier to recognize automobiles. The study employed both the LFW (Labeled Faces in the Wild) dataset to train the facial recognition algorithm and the CVC-09 dataset, which focused on vehicles. detection. The technology achieved an astonishing 98% accuracy in driver recognition in controlled circumstances and 90% in real-world conditions. In terms of vehicle detection, the system obtained 95% accuracy. Despite these excellent accuracy rates, the system's effectiveness was hampered by issues like poor illumination and partial facial occlusion. The study stressed the value of integrating facial recognition with vehicle detection to provide safe and efficient access management in both public and private transportation scenarios.

Further research looked into the feasibility of combining vehicle detection with driver behavior monitoring to improve traffic safety. The study used Haar Cascade Classifiers for vehicle recognition and deep learning models to analyze driver behavior in order to detect unsafe driving behaviors such as distracted driving or refusal to wear seat belts. The researchers used the KITTI Vision Benchmark Suite for vehicle detection and the DISFA (Denver Intensity Spontaneous Facial Actions) dataset to analyze facial expressions related to driver behavior. The system was able to detect vehicles with an accuracy of 98%, while driver behavior monitoring achieved an accuracy of 85% in identifying unsafe behaviors, such as texting while driving or failing to fasten a seatbelt. This integration of vehicle Driver behavior analysis shows promise for real-time traffic safety interventions, with potential uses in both self-driving cars and standard automobiles outfitted with advanced driver assistance systems (ADAS).

In another example, computer vision was used to identify indicators of driver weariness. Using CNNs and support vector machines (SVMs), the system identified symptoms of drowsiness in drivers. The system was integrated with R-CNN for vehicle detection, using the NTHU Driver Drowsiness Dataset for training the facial recognition model. The results indicated that the driver fatigue detection system was able to accurately identify drowsy drivers with 92% accuracy and automobiles with 98% accuracy. The study showed that this strategy might be useful for long-haul drivers, particularly those in commercial trucking, by delivering real-time notifications to minimize fatigue-related accidents.

Overall, the research reviewed emphasizes the rising relevance of computer vision in the development of intelligent systems for detecting both vehicles and drivers. Combining vehicle object detection with face recognition. for driver monitoring presents a powerful approach to enhance safety, optimize parking systems, and improve traffic flow. Despite the promising results, problems such as environmental conditions, sensor limitations, and privacy issues remain, potentially impeding wider implementation of these technologies. Further study is required to overcome these difficulties and increase the reliability and scalability of these systems in the actual world. scenarios[3], [4], [7], [9].

4. Vision-Based Parking Space Detection:

Over the last several years, there has been substantial improvement in the use of vision-based systems to detect unoccupied parking spaces. This has become a crucial component of intelligent parking systems designed to improve parking management, reduce congestion, and enhance the overall urban mobility experience. Vision-based techniques, particularly those that use computer vision and machine learning, have proven to be useful in recognizing empty parking spaces in real time. This section provides an overview of key research papers that address vision techniques for empty parking space detection, focusing on common approaches, technologies, and the main findings.

The majority of studies in the domain of vision-based parking space detection utilize various computer vision and deep learning approaches to detect empty parking spots. These approaches typically rely on image-based or video-based data captured from cameras placed in parking areas. The common methodologies and technologies employed across these studies include object detection, image segmentation, machine learning algorithms, and neural networks.

4.1. Object Detection and Classification

One of the most prevalent methods for finding empty parking spaces is object detection, which involves detecting automobiles occupying parking spaces. By detecting the presence of vehicles, the system can determine whether a place is empty or occupied. Popular deep learning models for object recognition, such as YOLO (You Only Look Once), Faster R-CNN (Region-Based Convolutional Neural Networks), and SSD (Single Shot Multibox Detector), have been employed extensively in parking space detection systems. These models are well-suited for real-time processing and can detect multiple objects within a single image or video frame.

For Example, Chien et al. (2020) used a YOLO-based object identification system to categorize parking spots as occupied or vacant. By evaluating images acquired by parking lot surveillance cameras, the system was able to recognize vehicles and classify spots. This method achieved an accuracy of 93% in recognizing vehicles and 90% in identifying vacant parking spaces.

4.2. Image Segmentation

Another widely used technique is image segmentation, which involves dividing an image into multiple regions or portions to assess their respective material. Image segmentation can be used to define the boundaries of parking spaces and determine if they are occupied by automobiles.

Several research have used semantic segmentation and instance segmentation approaches to detect parking spaces. Semantic segmentation adds a class label to each pixel in an image, whereas instance segmentation classifies pixels as well as distinguishes unique objects in the picture. DeepLabV3 and Mask R-CNN are both popular models used for segmentation tasks, and they have been effectively employed for detecting empty parking spaces by separating vehicle areas from parking spaces.

In a study by Liu et al. (2021), the authors employed semantic segmentation using a U-Net architecture, which is a convolutional neural network (CNN) model designed for segmentation tasks. The model was trained on a custom dataset of parking lot images and was able to detect empty spaces with high precision, achieving 88% accuracy in various parking environments.

4.3. Feature Engineering and Machine Learning

In addition to deep learning models, traditional computer vision approaches based on feature extraction and machine learning are widely used. These techniques usually include detecting important aspects like color, texture, or shape, which are then given into a machine learning classifier like Support Vector Machines (SVM), Random Forest, or K-Nearest Neighbors (KNN) for categorization.

For instance, Ravi et al. (2022) explored a combination of edge detection and color histogram-based feature extraction for identifying empty parking spots. They used SVM classifiers to distinguish between occupied and vacant parking spaces. While their approach was less computationally intensive than deep learning methods, it achieved promising results with a classification accuracy of 85% Vision-based parking space detection techniques, such as YOLO and Faster R-CNN, have demonstrated high accuracy in controlled environments. However, these systems often struggle with scalability and real-world challenges like variable lighting, weather conditions, and occlusions from closely parked vehicles. Many datasets, such as PKLot, primarily focus on static parking lots and lack diversity, limiting their ability to train models for dynamic urban scenarios. For example, real-world parking systems must handle challenges like multi-level garages, street parking, and nighttime conditions, which are often underrepresented in current datasets. The City Parking Dataset addresses some of these issues but still falls short in covering weather variations and unconventional parking layouts. To improve, researchers should use more diverse datasets that include varied environments and conditions. Addressing these limitations is key to making vision-based parking systems more scalable and reliable in real-world applications.[13], [22], [27], [28], [29] .

4.4. Hybrid Approaches

Some studies have used hybrid approaches, combining classic computer vision algorithms with deep learning techniques to improve parking spot recognition. A hybrid technique typically combines object recognition for real-time vehicle identification with picture segmentation to appropriately label empty spaces.

Zhang et al. (2023) used YOLO to detect vehicles and a Mask R-CNN to segment parking spots. The hybrid model enhanced accuracy and robustness by integrating the advantages of both object detection and segmentation. The system showed a marked improvement in detecting empty spaces, with an accuracy of 95% in urban parking environments.

4.5. Datasets Used for Parking Space Detection

The success of vision-based parking space detection systems heavily relies on the quality and diversity of the datasets used for training and evaluation. Several datasets have been commonly used in the literature to benchmark these systems:

- **PKLot**: A publicly available dataset used in many parking space detection studies. It contains labeled images of parking lots under different lighting and weather conditions, allowing researchers to test the robustness of their models.
- **CURET**: This dataset includes parking lot images captured at various angles and times of day. It is often used for object detection tasks.

- **Parking Lot Dataset**: A custom dataset created by some studies that contains a large number of parking lot images with labeled spaces for detecting vacant spots. This dataset is particularly useful for training segmentation models.
- **City Parking Dataset**: A dataset that includes images from urban parking areas, used to test detection systems under complex, real-world scenarios.

4.6. Findings from Recent Studies

The findings from recent studies emphasize the high potential of computer vision techniques for real-time parking space detection. The following key insights have emerged:

1. High Accuracy in Controlled situations: Research has demonstrated that deep learning models such as YOLO and Faster R-CNN produce high accuracy rates (over 90%) when recognizing unoccupied parking spaces in controlled or semi-controlled situations, such as parking lots with fixed camera sets[30].
2. Challenges in Real-World Scenarios: Real-world applications often face challenges such as variable lighting, occlusion of vehicles, and crowded parking lots, which can reduce the performance of vision-based systems. Models trained on diverse datasets, including images from different weather conditions and times of day, have shown improved robustness[31].
3. Real-Time Processing: Numerous research has proved the capacity to detect parking spaces in real time, with systems reaching processing rates acceptable for use in smart parking systems. However, computational cost remains an issue for large-scale applications[18].
4. Hybrid Models for Improved Accuracy: Combining object identification and image segmentation has shown to be a successful method for detecting empty parking spaces. Hybrid techniques can assist reduce false positives and enhance the identification accuracy of free spaces, particularly in complicated parking situations[32].
5. The quality of the dataset has a significant impact on the accuracy of the parking space recognition algorithm. Models trained on different datasets with varying lighting, weather, and parking lot configurations perform better in real-world conditions[20].

5. Critical Review

5.1 Critical Review of Vision-Based Applications for Driver and Vehicle Detection:

Recent advances in vision-based applications for driver and vehicle identification have resulted in significant progress in the development of intelligent transportation systems (ITS), but some hurdles remain. As autonomous vehicles and smart parking systems become more common, the incorporation of computer vision (CV) technologies such as object identification, facial recognition, and license plate recognition is critical for enhancing safety, traffic efficiency, and parking management. Despite the promising applications, broad adoption of AI-based solutions for these jobs remains hampered by a few constraints, including environmental adaptation, processing efficiency, and privacy concerns.

The increasing reliance on deep learning models, particularly convolutional neural networks (CNNs), has been a defining factor in the ability to detect vehicles and drivers from real-time video feeds. Studies have demonstrated the effectiveness of CNNs in detecting vehicles under varying conditions, with some systems achieving accuracy rates as high as 96%. This ability to perform detection despite environmental challenges, such as poor lighting and weather, represents a significant leap forward in the development of autonomous systems. Additionally, facial recognition systems have shown potential for real-time identification of drivers, contributing to enhanced safety and personalized vehicle access control. However, this combination of technologies often encounters difficulties when dealing with obscured facial features, poor visibility, and severe angles, limiting the overall robustness of these systems.

When investigating the integration of object detection and optical character recognition (OCR) for smart parking applications, research shows that systems using both technologies can improve parking space utilization by identifying automobiles and scanning license plates. YOLO (You Only Look Once) for object detection and OCR for license plate identification have demonstrated high accuracy rates. (94% for vehicle detection and 88% for license plate recognition), the success of such systems is still heavily reliant on ideal conditions. The practicality of deploying these systems in dynamic, high-demand urban settings require overcoming challenges related to environmental factors, sensor limitations, and scalability.

Furthermore, advancements in driver behavior analysis, particularly through facial expression recognition, offer potential improvements in traffic safety by enabling systems to identify unsafe behaviors such as distracted driving or Failure to wear seatbelts. The combination of these systems with vehicle detection technologies could allow for real-time intervention in critical situations, resulting in instant safety gains. However, while these systems show promise with high accuracy in controlled settings, their performance can decline in less controlled contexts, such as conditions of partial face occlusion or fluctuating levels of illumination.

Another crucial area of research is the identification of driver weariness, which has been identified as a significant contributor to traffic accidents. Vision-based systems that combine CNNs and support vector machines (SVMs) have shown promise in identifying tiredness by evaluating facial expressions and behavioral signs. Though accuracy rates in detecting driver fatigue have reached impressive levels (92% for drowsy driver detection), the effectiveness of these systems is still limited by sensor limitations, such as the reliance on cameras, which may not always provide clear or consistent data in real-world conditions.

Despite these advancements, the widespread application of AI and computer vision technologies in driver and vehicle identification is still limited due to a number of underlying problems. Environmental variability—for example, changes in meteorological conditions, lighting, or the presence of obstructions—still poses a significant hurdle to the consistent performance of these systems. Additionally, the **scalability** of these technologies in real-world scenarios, particularly in busy urban environments or large-scale parking facilities, continues to require significant computational resources and sophisticated sensor integration. Privacy concerns associated with facial recognition and data security issues further complicate the broader adoption of these technologies, necessitating clear regulations and user consent protocols[30], [31], [32].

5.2 Critical Review of Vision-Based Parking Space Detection

The application of computer vision (CV) and deep learning techniques in detecting empty parking spaces has gained significant attention in recent years. Numerous studies have shown the potential of these technologies to improve parking management systems, reduce congestion, and enhance urban mobility. While the existing research has yielded promising results, it also reveals several limitations and challenges that must be addressed to improve the robustness, Scalability and practical use of vision-based parking spot detecting systems. This critical evaluation assesses the evaluated studies' strengths and limitations, compares techniques, datasets, and results from various research endeavors, and finds reoccurring obstacles and unresolved concerns in the field.

One of the evaluated studies' key strengths is the excellent detection accuracy attained in controlled situations. Many of the research used deep learning models, including YOLO (You Only Look Once) and Faster R-CNN, to detect vehicles in parking lots. These models have demonstrated great performance, with accuracy frequently reaching 90%. especially when the systems are deployed in settings with consistent lighting, fixed camera placements, and minimal environmental disruptions. For instance, the use of YOLO for object detection has been effective in classifying parking spaces as occupied or vacant with high precision in ideal conditions. This high accuracy is a key advantage of deep learning approaches, as they can handle complex visual patterns and provide real-time processing capabilities, which is crucial for parking management applications.

Furthermore, the ability to perform real-time processing is another notable strength of the studies reviewed. Many Systems demonstrated the ability to detect empty parking spots and categorize vehicle occupancy within seconds, which is an important characteristic for dynamic parking settings. Real-time detection is especially relevant in metropolitan settings, where traffic flow and parking demand vary throughout the day. The models used in these experiments were frequently capable of processing images quickly, making them ideal for use in smart parking systems that demand immediate choices. For example, the combination of YOLO and quick object identification algorithms ensured that parking spaces could be monitored and classified efficiently, minimizing waiting times for drivers.

Another positive trend in the research is the adoption of hybrid models that combine object detection with image segmentation techniques. These hybrid approaches, particularly the use of Mask R-CNN alongside object detection models like YOLO, have proven beneficial in complex parking environments. By segmenting parking spaces and detecting vehicles within those segments, hybrid models reduce the occurrence of false positives and improve the accuracy of detection in challenging scenarios, such as when vehicles are parked closely together or in irregular configurations. These approaches have been successful in improving the precision of parking space detection, particularly in environments where the layout is not uniform, or vehicles obscure the view of some spaces.

Despite these strengths, several limitations and challenges persist in the field of vision-based parking space detection. One of the most prominent limitations is the real-world variability that can affect system performance. Although many of the studies demonstrated high accuracy in controlled environments, the systems often struggle to maintain performance in dynamic, real-world conditions. Environmental factors such as lighting changes, weather conditions (e.g., rain, fog, snow), and occlusion (vehicles blocking the view of parking spaces) can significantly impact the reliability of detection systems. For instance, parking systems that perform well under clear skies and bright lighting may fail when light levels drop or when adverse weather conditions obscure the camera's view. These challenges highlight a key gap in the current research: the need for more robust models that can handle such environmental Variability is used efficiently.

Another problem in current research is a lack of dataset diversity. Many studies have used common datasets such as PKLot, CURET, and City Parking, which, while useful, frequently lack the diversity required to ensure robust performance in real-world circumstances. These datasets are usually restricted to specific parking conditions (such as well-lit, urban, or residential locations), vehicle types, or parking lot layouts. As a result, models trained on such datasets may not generalize well in new or unfamiliar situations, such as multi-level parking garages. outdoor street parking, or areas with unusual vehicle configurations. Additionally, these datasets often fail to capture the full range of environmental conditions (e.g., varying light levels, different weather scenarios), which are crucial for developing more generalized and adaptable parking detection systems.

The issue of scalability also remains a significant challenge. While many studies show promising results in small-scale parking scenarios, there is limited research on how these systems perform in large-scale, real-world deployments. For example, the effectiveness of parking space detection systems in large urban parking lots, or on-street parking in a city, has not been fully explored. The integration of multiple cameras, the coordination of data from different sensors, and the scalability of the model to cover large areas are key factors that need further investigation. As the parking demand in urban areas increases, scalability will be critical for ensuring that these systems can handle real-time parking detection over wide areas without compromising on accuracy or processing speed.

A related issue is the absence of long-term evaluations. The majority of the examined papers concentrated on short-term experiments or simulations, with little consideration given to how these systems operate over longer durations. Real-world parking lots are dynamic settings in which vehicle occupancy patterns change over time and parking lot layouts can be altered. There is a gap in the literature about how well vision-based systems can adapt to such changes and how they perform over the long term in environments where the conditions evolve, such as with the introduction of new vehicles, the reorganization of spaces, or changing traffic patterns[3], [16], [21], [33], [34].

Another unresolved issue in the field concerns the privacy and security of vision-based systems. While not always discussed in the reviewed studies, the use of cameras to monitor parking lots raises important concerns about data privacy, particularly when facial recognition technology is used for driver identification. These concerns are heightened by the growing regulatory landscape, such as the General Data Protection Regulation (GDPR) in Europe, which places strict limits on the collection and processing of personal data. Ensuring that these systems comply with privacy regulations while still providing accurate and reliable detection will be an ongoing challenge as these technologies become more widely deployed.

Finally, while machine learning and deep learning approaches have demonstrated high accuracy in many cases, the computational cost and the need for specialized hardware remain significant barriers to widespread adoption. Models like YOLO and Faster R-CNN require powerful processing units and large datasets for training, which can be a limiting factor in resource-constrained environments. This trade-off between performance and computational cost is an area that requires further exploration to develop more efficient models that can be deployed in a broader range of Applications include low-cost parking options for small communities and private establishments.

To summarize, while vision-based parking space identification systems have shown great potential, the area still confronts significant obstacles. The current research's strengths are the great accuracy attained in controlled situations, as well as the development of hybrid models that combine object detection and segmentation algorithms. However, there are concerns about environmental unpredictability, dataset constraints, scalability, long-term evaluation, privacy, and computational efficiency remain unresolved. Future research should focus on improving the robustness and generalizability of these systems, exploring new datasets that capture real-world complexities, and developing scalable and privacy-compliant solutions that can be effectively deployed in dynamic urban environments.

6. Discussion

The review of vision-based techniques for detecting empty parking spaces reveals several important trends, innovations, and potential future directions in the field. This section synthesizes the key insights drawn from the reviewed studies and discusses their implications for both the academic research community and real-world applications. Additionally, possible solutions to the identified gaps will be proposed.

6.1. Key Trends and Innovations

1. Advances in Deep Learning Models: One of the most noticeable trends in the reviewed studies is the widespread use of deep learning models for parking space detection, particularly object detection models like YOLO (You Only Look Once), Faster R-CNN, and SSD (Single Shot Multibox Detector). These models have significantly improved detection accuracy and speed, making them ideal for real-time parking management applications. These models are capable of detecting and classify vehicles in various environmental conditions has marked a major innovation in the field, offering a robust solution for dynamic and large-scale parking systems.
2. Integration of Hybrid Approaches: Another important innovation is the integration of object detection and Image segmentation techniques. Hybrid models, such as YOLO for vehicle recognition and Mask R-CNN for segmentation, have been used successfully to handle difficult parking circumstances. These methods improve the accuracy of parking space recognition, especially in congested or irregular parking lots where

vehicles may overlap or cover available spaces. This shift toward hybrid models marks a considerable step forward in addressing the issues of parking space detection in real-world environments.

3. Real-Time Processing and Efficiency: The trend of real-time processing in vision-based parking space detection is a crucial innovation. Many systems are now capable of processing images at near-instantaneous speeds. This allows smart parking systems to give drivers with real-time availability updates. This is critical in urban areas because parking demand changes frequently and quickly. Studies have shown that models can detect unoccupied parking spaces in a fraction of a second, increasing user experience and optimizing parking resource distribution in real time.
4. Use of Segmentation for Improved Accuracy: While object detection has made great strides, the use of image segmentation has emerged as a key innovation to further improve detection accuracy, especially in scenarios with complex parking lot layouts or closely parked vehicles. Semantic and instance segmentation, often powered by deep learning models like U-Net and DeepLabV3, has proven effective in delineating parking spaces and identifying vacant spots amidst challenging visual contexts. These methods allow for more precise identification of available spaces, reducing the risk of misclassification[8], [35], [36] .

6.2. Implications for the Field and Real-World Applications

The findings from the reviewed studies have significant implications for both the academic research community and real-world applications in urban mobility and smart cities. First, the advancement of deep learning and hybrid models for parking space detection offers a promising solution to urban parking challenges. Real-time parking space monitoring and management can reduce congestion, improve parking space utilization, and minimize the environmental impact of driving in search of parking. In busy urban areas, where parking demand often outstrips supply, such systems could help alleviate traffic congestion and improve the overall flow of traffic.

Additionally, the development of more accurate and robust parking detection systems has the potential to enhance the user experience. For instance, smart parking apps that rely on computer vision could provide drivers with up-to-date information on available parking spots, reducing the time spent searching for parking and, ultimately, contributing to reduced fuel consumption and emissions.

The ramifications go beyond parking management. Vision-based systems may be used with other smart city technologies to build a more connected and efficient urban infrastructure. For example, combining parking detection systems with real-time traffic management systems, electric vehicle (EV) charging stations, or public transportation networks could result in a smooth and efficient multimodal transportation environment.

6.3. Proposing Solutions to Identified Gaps

1. Multi-Sensor Integration: To address the challenge of environmental variability, future systems should integrate multiple sensors (e.g., LiDAR, infrared, radar) alongside traditional cameras. Multi-sensor fusion

can provide a more comprehensive understanding of the parking environment, allowing for more accurate detection in adverse conditions, such as poor lighting or inclement weather.

2. Adapting to Dynamic Parking Scenarios: To overcome scalability challenges, future research should explore adaptive learning models that can evolve and improve over time as they encounter new parking environments. These models could be fine-tuned on real-time data collected from deployed systems, making them adaptable to dynamic parking conditions, such as changes in traffic patterns, parking lot layouts, or the addition of new vehicles.
3. Expanding Datasets and Benchmarking: There is a critical need for larger and more diverse datasets that better reflect real-world parking scenarios. These datasets should include a wide variety of environmental conditions, camera angles, and vehicle types. Moreover, future research should establish standardized benchmarking metrics to assess the performance of parking space detection systems across various conditions and environments, ensuring consistency and comparability across studies.
4. Privacy-Preserving Techniques: As privacy concerns grow, the development of privacy-preserving algorithms is essential. Techniques like edge computing, where data processing happens locally rather than in cloud, can help minimize the amount of sensitive data transmitted. Additionally, privacy laws must be adhered to in any deployment of such systems, especially when personal data, such as vehicle license plates or facial recognition data, is involved[10], [14], [37].

7. Conclusion

The review of vision-based techniques for detecting empty parking spaces highlights the significant advancements made in the field of intelligent parking systems. The application of deep learning models, such as YOLO and Faster R-CNN, has shown remarkable success in detecting vehicles and classifying parking spaces in controlled environments. These models have demonstrated high accuracy and real-time processing capabilities, making them well-suited for use in smart parking systems that aim to reduce congestion and optimize parking space utilization in urban settings.

A key innovation identified in the review is the integration of object detection with image segmentation techniques, such as Mask R-CNN, which enhances the accuracy of parking space detection, particularly in complex environments. This hybrid approach improves the reliability of detecting empty spaces, even when vehicles are parked close together or when parking layouts are irregular.

However, the review also highlights several limitations in the current body of research, particularly related to the real-world applicability of these systems. The variability in environmental conditions, such as lighting changes, weather, and occlusion, remains a significant challenge. Additionally, the generalization of models to diverse, real-world parking environments is hindered by the limited diversity of existing datasets, which often fail to capture the full range of parking scenarios and conditions.

7.1. Contribution of Our Work to the Field

Our work contributes to the ongoing research in vision-based parking space detection by addressing some of the identified gaps. Specifically, we focus on enhancing model robustness to diverse environmental conditions through multi-sensor integration. By combining computer vision with LiDAR or radar sensors, we aim to improve detection accuracy in poor lighting conditions and adverse weather scenarios, where traditional camera-based systems might fail. Furthermore, we contribute to the construction of more generalizable models by utilizing a more diversified dataset that includes a variety of parking sites, car kinds, and real-world scenarios. This helps overcome the barrier of dataset restrictions and ensures that the model can execute dependably. in a variety of parking situations, from residential garages to urban street parking.

7.2. Future Research Opportunities

As parking management systems continue to evolve, several areas present significant opportunities for enhancing the capabilities of vision-based parking space detection. Despite considerable progress, there are still notable gaps that must be addressed to ensure these systems can effectively handle the complexities of real-world environments. The next generation of smart parking solutions will need to be adaptable to various conditions, scalable to larger urban infrastructures, and compliant with privacy regulations:

1. **Enhancing Robustness in Variable Environments**: Future research should focus on improving detection Accuracy under difficult real-world conditions like as changing lighting, inclement weather, and occlusion from other vehicles. Integrating many sensor types, such as cameras, LiDAR, and radar, and infrared, could provide more reliable data and enhance system performance in diverse environments.
2. **Long-Term and Scalable Deployments**: Most current studies have been short-term and focused on Controlled environs. Long-term, real-world evaluations are required to assess system performance over time, particularly in large-scale metropolitan contexts where parking conditions change and vehicle types shift.
3. **Expanding and Diversifying Datasets**: Existing datasets provide a limited range of parking scenarios and car kinds. To improve generalizability, future research should emphasize the production of more diverse datasets that cover a variety of parking situations (e.g., multi-level garages, street parking), vehicle types (e.g., electric vehicles, trucks), and environmental conditions.
4. **Addressing Privacy and Ethical Concerns**: As camera-based systems and vehicle identification As technologies become more widely used, protecting privacy and data security will become increasingly important. Future research should concentrate on privacy-preserving techniques, such as edge computing for local data processing, to reduce risks and assure compliance with privacy legislation such as GDPR.
5. **Adaptive Learning for System Evolution**: Parking environments are dynamic, and detection systems need to adapt to changes over time. Research should explore adaptive learning techniques that enable systems to

update their models in real-time based on new data, ensuring continued accuracy as parking layouts, vehicle types, and user behaviour evolve.

In conclusion, while the field of vision-based parking space detection has made substantial progress, challenges remain in terms of robustness, scalability, and real-world applicability. Our work addresses some of these challenges and contributes to the development of more reliable and generalizable parking space detection systems. Future research should focus on improving the integration of sensors, expanding datasets, and developing privacy-preserving techniques, all of which will pave the way for smarter and more efficient urban parking solutions[13], [22], [26], [27], [28].

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