

**INSTITUTE OF MANAGEMENT SCIENCES (Pak-Aims)**

**Title of Thesis**

Real Time Car Parking Occupancy Prediction System

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# **Abstract**

Parking management systems are crucial for managing the increasing number of vehicles in urban areas, contributing to the development of smart cities. The efficiency of such systems relies heavily on the accuracy of parking lot occupancy detection algorithms. Traditionally, neural network classifiers applied to camera recordings have been employed for this purpose. However, these existing systems have shown limitations in terms of generalization and performance under specific visual conditions in real-world scenarios.

Most of the research papers presents a comprehensive evaluation of state-of-the-art parking lot occupancy detection algorithms and compares their performance with emerging vision transformer models. The proposed approach utilizes the EfficientNet architecture, demonstrating improved metrics over existing methods. The evaluations encompass five diverse datasets, including a novel seasonal parking lot dataset (SPKL) that includes winter images and various visual occlusions representative of real-world scenarios. Additionally, existing datasets are extended with additional visual condition labels and standardized storage format.

The main contributions of this study include an extensive evaluation of existing architectures, introduction of the SPKL dataset, extension of existing datasets with visual condition labels, and a novel approach based on the EfficientNet architecture.

The introduction highlights the challenges posed by increasing urban vehicle populations and the importance of parking guidance systems. It outlines the proposed research's objectives, which involve leveraging computer vision and intelligent algorithms to create a real-time car parking occupancy prediction system with location awareness. The objectives aim to improve efficiency, illumination factors, incorrect parking placement, parking allocation, and cost efficiency issues, as well as enhance slot allocation using real-time data, intelligent slot management, dynamic slot availability, and user interaction.

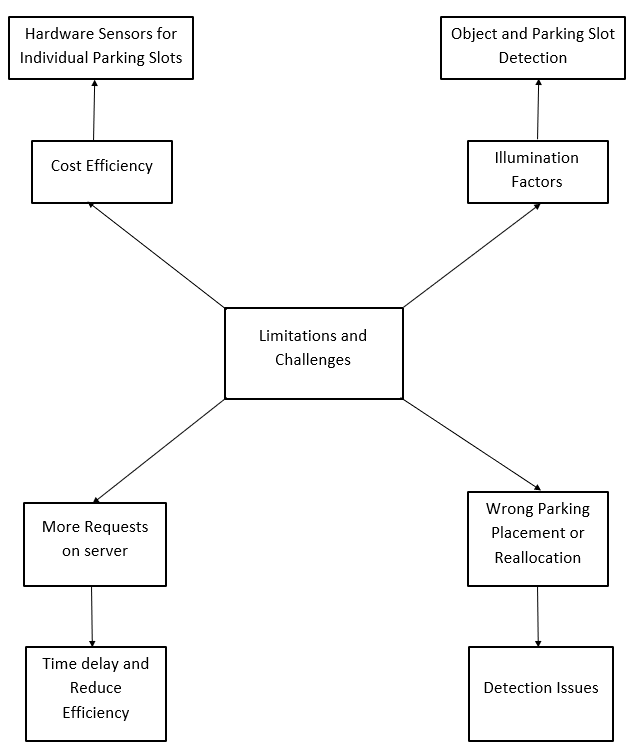
The research statement emphasizes the significance of addressing parking occupancy detection challenges in urban areas and presents the primary research objectives. The scope of the study is confined to deterministic closed parking environments, and the methodology involves the use of computer vision algorithms, convolutional neural networks (CNNs), and reinforcement learning techniques.

In conclusion, the proposed research aims to develop an advanced Real-Time Car Parking Occupancy Prediction System that enhances parking management efficiency and improves user experience in urban environments. The system's integration with mobile applications and surveillance cameras ensures seamless parking operations, benefiting both users and parking managers. The research will contribute to the field of computer vision and intelligent parking systems, offering practical solutions for efficient parking management in urban areas while considering real-world deployment challenges and scalability.

# **Introduction**

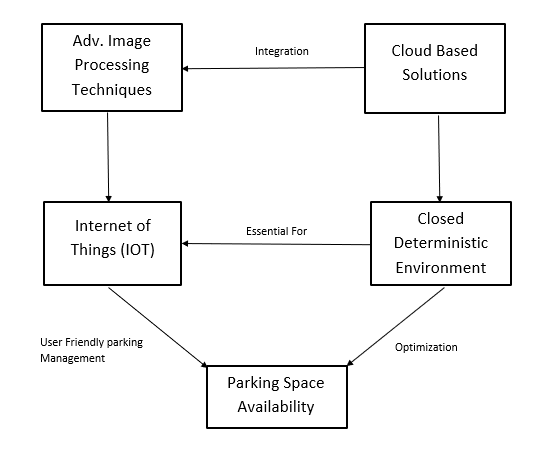
The escalating urbanization and increasing vehicle ownership have led to a critical issue of parking space scarcity in urban areas. This challenge is expected to intensify in the coming years, posing significant implications for urban mobility and quality of life. While several approaches have been explored to tackle this problem, a comprehensive and effective solution remains elusive.

Previous research has examined various methods to address parking space scarcity, including hardware sensors for individual parking spaces and Computer Vision (CV) technology. However, these approaches often lack holistic integration and do not cater to the specific requirements of closed deterministic parking scenarios, commonly found in malls, hospitals, and residential complexes. These scenarios require a tailored solution due to security and environmental considerations. In previous research for object detection lot of requests were directly hit on server on every detection that caused time delay and reduce efficiency. Illumination factors were also involved that caused issues in object and license plate number detection due to open street parking. Cost efficiency were also another issue in past studies as the hardware used was enough expensive to implement. Another major limitation was reported in previous studies was the wrong parking placement detection and parking reallocation issues. Figure 1 shows the limitations and challenges.



**Figure 1.** Limitations and Challenges

The research problem stems from the gap in existing literature, which lacks a comprehensive solution that effectively integrates advanced image processing techniques, Internet of Things (IoT) technology, and cloud-based solutions to optimize parking slot allocation and management within closed deterministic environments. The integration of these technologies is essential to create a seamless and user-friendly parking management system that addresses parking space availability challenges, enhances user experience, and promotes efficient management as shown in Figure 2.



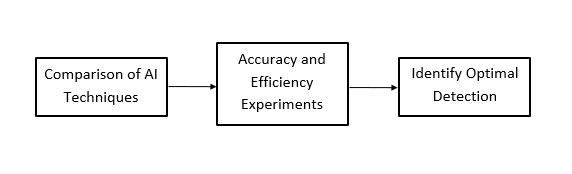
**Figure 2.** Advance Techniques to optimize parking slot Allocation

The comprehensive objectives of this research are centered around evaluating and analyzing the strengths and weaknesses of various state-of-the-art deep learning architectures, specifically vision transformers and convolutional neural networks (CNNs), within the context of parking lot occupancy detection. The research aims to conduct an in-depth exploration of these architectures to gain insights into their performance characteristics, advantages, and limitations when applied to the challenging task of detecting parking space occupancy.

The primary objective is to systematically compare the performance of vision transformers and CNNs for parking lot occupancy detection. This involves designing rigorous experiments to quantify the accuracy, efficiency, and adaptability of each architecture under diverse visual conditions, including poor lighting, occlusions, and different weather scenarios. By meticulously assessing the strengths and weaknesses of these architectures, the research intends to provide a comprehensive understanding of how they handle challenging real-world scenarios.

Furthermore, the research aims to identify the optimal architecture that aligns with the specific requirements of parking lot occupancy detection. Through a meticulous analysis of the experimental results, the research aims to determine which architecture exhibits superior accuracy, robustness, and generalization capabilities. These findings will guide the selection of the most suitable deep learning architecture to be employed in the proposed algorithm, ensuring that the chosen architecture can effectively address the challenges associated with parking lot occupancy detection in adverse visual conditions.

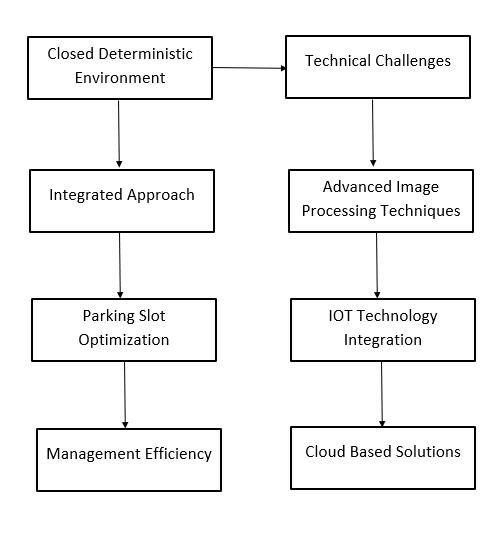
The research aims to contribute valuable insights into the selection of deep learning architectures for parking lot occupancy detection. The results of this analysis will not only guide the development of the proposed algorithm but also provide a broader understanding of the applicability and limitations of different architectures in the context of computer vision tasks. As shown in Figure 3, the research aims to advance the state-of-the-art in parking lot occupancy detection by leveraging the strengths of deep learning architectures to enhance accuracy and efficiency while mitigating the impact of challenging visual conditions.



**Figure 3.** Optimal Detection in Visual Conditions

The research focuses specifically on closed deterministic parking environments, such as malls, hospitals, and residential complexes. These scenarios are chosen due to their unique security and environmental considerations, making them suitable for the proposed integrated solution. The research will employ a combination of theoretical analysis, algorithm development, experimentation, and case studies to achieve the research objectives.

The research endeavors encompass a multi-faceted exploration, aiming to provide a comprehensive integrated solution that optimizes parking slot allocation and management within the confines of closed deterministic environments. This initiative extends its scope to encompass insights into the intricate technical challenges associated with the seamless integration of advanced image processing techniques, Internet of Things (IoT) technology, and cloud-based solutions as shown in Figure 4. By delving into these complexities, the research seeks to enhance our understanding of the potential impact of the proposed solution. This includes its capacity to not only enhance parking slot allocation precision but also to significantly reduce waiting times, elevate overall user satisfaction, and effectively harness parking space utilization. The synthesis of these facets endeavors to create a holistic approach that not only addresses the technical intricacies but also empowers urban environments to achieve efficient and user-centric parking management systems.



**Figure 4.** Advance Solutions for parking optimization

The research problem revolves around addressing the challenge of parking space scarcity in closed deterministic environments through the integration of advanced image processing techniques, IoT technology, and cloud-based solutions. The research seeks to develop a transformative solution that enhances urban mobility, mitigates parking-related challenges, and contributes to a more sustainable and efficient urban environment. The proposed integrated solution holds the potential to revolutionize parking management, improve user experience, and pave the way for more effective and user-centric parking solutions.

## Background of Study

**1.1.1 (Martynova, Kuznetsov, Porvatov, & Tishin, 2023)** encompasses a range of substantial contributions and accomplishments, focused on addressing the challenges and limitations in the field of parking lot occupancy detection.

The research initiated with an exhaustive evaluation of existing architectures and methods employed in parking lot occupancy detection. By re-implementing and analyzing prominent algorithms, a comprehensive understanding of their strengths and limitations was established. This evaluation serves as a cornerstone for the subsequent developments in the study.

Recognizing the deficiencies in available datasets, a novel dataset named the Seasonal Parking Lot (SPKL) dataset was created. This dataset addresses the shortcomings of existing datasets by encompassing diverse visual conditions such as winter imagery and various types of natural occlusions. The annotations for this dataset were meticulously generated using specialized widgets developed for this purpose.

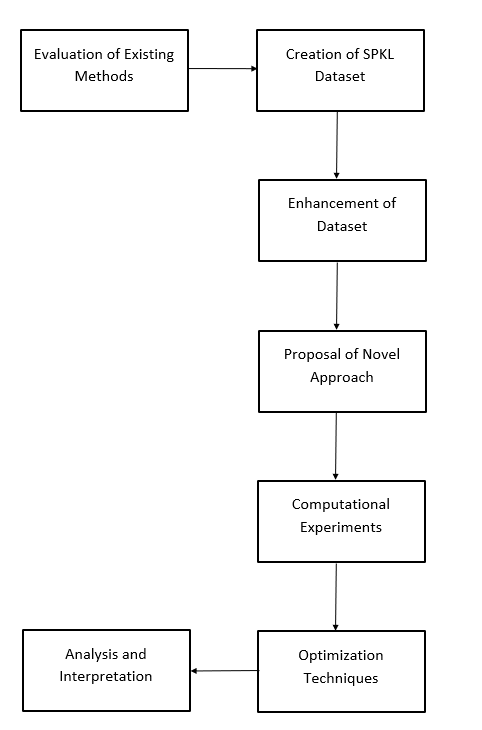
In addition to the creation of the SPKL dataset, efforts were dedicated to enhancing the usability of existing datasets. This involved augmenting these datasets with additional visual condition labels and standardizing their storage format. This enhancement contributes to the comparability and consistency of evaluations across various methodologies.

One of the significant achievements of this research is the proposal of a novel approach for parking lot occupancy detection. This approach leverages the well-established EfficientNet architecture as its foundation. Extensive investigations were conducted to explore the effectiveness of this approach under different configurations and scenarios. The proposed method's performance was compared against existing methods, demonstrating promising results in terms of accuracy and generalization capabilities.

The research involved a comprehensive series of computational experiments, spanning a wide range of approaches, architectures, and datasets. The experiments provided a robust assessment of the proposed novel approach, alongside established methodologies, vision transformers, and convolutional neural networks. The results obtained from these experiments were meticulously analyzed to extract insights into the strengths and limitations of each method.

Beyond the core experiments, the research delved into the optimization and enhancement of the proposed novel approach. Various techniques were explored, including grouped convolutions, residual connections, alternative optimizers, exponential moving average, batch accumulation, and batch-independent normalization. These techniques were systematically applied and evaluated to identify their impact on the performance of the approach.

As shown in Figure 5, the findings from the computational experiments were subject to thorough analysis and interpretation. The research provided insights into the performance variations across different datasets, visual conditions, and methodologies. Additionally, the analysis shed light on the strengths and weaknesses of the proposed approach and its competitors.



**Figure 5.** Martynova Challenges and Limitations in parking lot occupancy detection

**1.1.2 (Marek & Martin, 2021)** encompasses a comprehensive exploration of the domain of object detection in parking lots. The major work done in this research revolves around the creation of a new dataset, the design and training of object detection models, and the evaluation of these models for parking space occupancy classification.

The research involves the creation of a novel dataset called Action-Camera Parking Dataset (ACPDS). This dataset is distinct from prior datasets as it captures images from unique viewpoints, systematically annotates parking spaces, and employs separate parking lots for training, validation, and testing. By capturing images from a variety of parking lots, weather conditions, and lighting scenarios, the dataset mimics real-world challenges. This dataset allows for comprehensive testing of model generalization, performance on unseen parking lots, and the impact of occlusions and lighting variations.

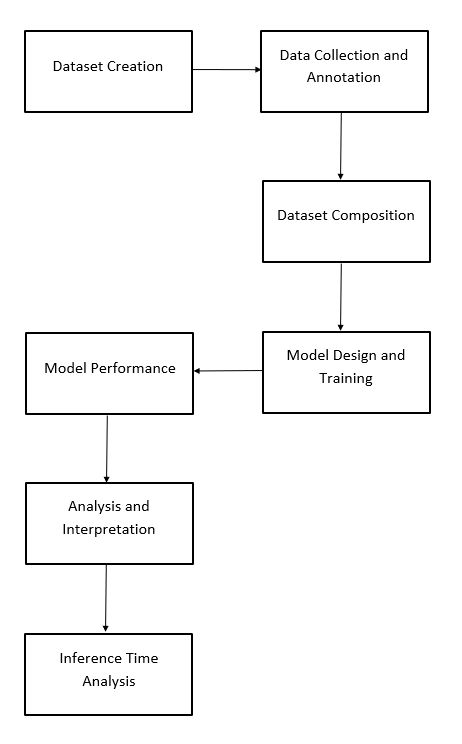
The research is dedicated to the development and implementation of two object detection models with a distinct focus on accurate parking space occupancy classification. The first model, designated as the R-CNN Architecture, draws inspiration from previous studies in image-based parking space occupancy classification. This model involves the extraction of image patches directly from parking space regions, which are then subjected to classification using a binary classifier (ResNet50). This approach capitalizes on pooling techniques and leverages the model's inherent architectural flexibility.

The second model, known as the Faster R-CNN FPN Architecture, builds upon the foundation of the Faster R-CNN FPN architecture. By utilizing a ResNet50 backbone in conjunction with a feature pyramid network, this model effectively gathers features from individual parking spaces. Subsequently, these pooled features undergo classification through a designated classification head to predict occupancy status. A remarkable feature of this model's architecture is its ability to facilitate information exchange between parking spaces, thereby aiding in the process of occlusion reasoning.

Both proposed models are trained on the newly created ACPDS dataset. Various hyperparameter configurations are explored during training. The models are trained using the AdamW optimizer and undergo augmentation techniques such as random flips, rotations, and brightness adjustments. The research compares different pooling methods, resolutions, and architectures to optimize performance.

The trained models are evaluated using the validation and test sets of the ACPDS dataset. Comparison between the models reveals that the Faster R-CNN FPN architecture generally outperforms the R-CNN architecture, showcasing better generalization to unseen parking lots and occlusion reasoning capabilities. Inference time analysis shows that the R-CNN architecture is more suitable for practical deployment due to its flexibility with different resolutions.

The research provides valuable insights into the challenges of object detection in parking lots as shown in Figure 6, particularly in real-world scenarios with occlusions and diverse lighting conditions. The dataset and models introduced by Marek not only contribute to the state-of-the-art in parking space occupancy classification but also lay the foundation for future advancements in this field. The research also highlights the potential for using high-resolution cameras and various architectural choices to improve the accuracy and efficiency of parking space detection models.



**Figure 6.** Marek comprehensive exploration of object detection in parking lots

**1.1.3 (Sudhakar, Reddy, Mounika et al., 2021)** expresses an urgent need for efficient parking space management. In this research, he delves into the development of a Smart Parking Management System that leverages object detection and parking occupancy detection technologies to address this challenge. The system offers real-time insights into parking space availability, enhances user convenience, and optimizes parking space utilization.

Central to the system's architecture is the utilization of advanced object detection techniques. He employs a combination of hardware components and image processing algorithms to accurately identify vehicles and determine their presence within parking slots. The system employs a Raspberry Pi as the processing unit, equipped with a camera module for capturing images of the parking lot entrance.

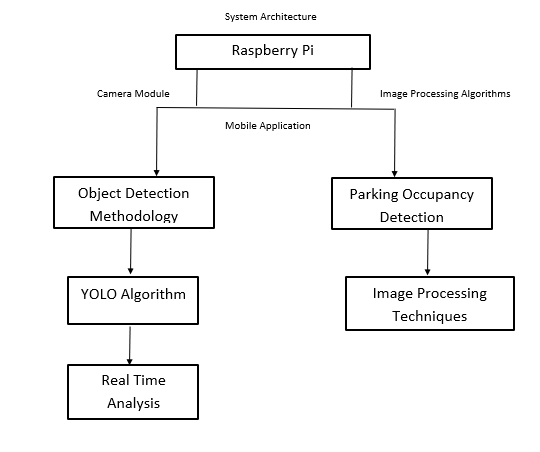
The object detection process involves real-time analysis of images captured by the camera module to utilize state-of-the-art object detection algorithms, such as YOLO (You Only Look Once), to rapidly identify vehicles within the images. This detection enables us to ascertain the occupancy status of individual parking spaces.

Upon successful object detection, the system employs advanced image processing techniques to analyze the images and determine the occupancy status of parking slots. This process involves identifying the contours and shapes of vehicles within the images. By evaluating these factors, the accurately determine whether a parking slot is occupied or vacant.

The system's real-time parking space availability information is relayed to users through a mobile application. This application serves as a user-friendly interface, displaying the status of each parking slot in the parking lot. Users can conveniently access up-to-date information about available parking spaces, minimizing the time and effort spent searching for vacant spots.

The research assesses the accuracy and effectiveness of the object detection and parking occupancy detection processes. Through various scenarios to validate the system's ability to reliably detect vehicles, accurately determine parking occupancy, and promptly update parking availability information.

The research identifies several avenues for enhancing the object detection and parking occupancy detection aspects of the system as shown in Figure 7. Further refinement of object detection algorithms and incorporation of machine learning techniques could lead to even more precise vehicle identification. Additionally, the integration of multi-sensor data could enhance the system's robustness under diverse lighting and weather conditions.



**Figure 7.** Sudhakar highlights Challenges and Limitations for efficient parking space management

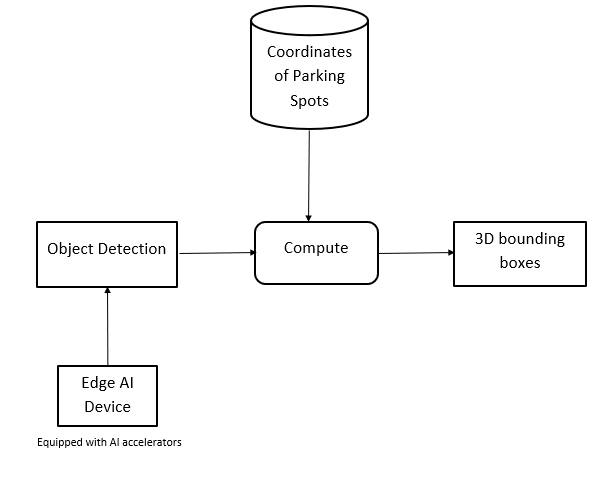
**1.1.4 (Stojanović, Damjanović, Vukmirović et al., 2021)** addresses the critical challenges of parking occupancy in urban environments. With the global increase in vehicles, effective solutions are needed. While various methods have been explored, the researchers assert that Computer Vision (CV) holds the key to accurate parking occupancy prediction.

The researchers propose an innovative architecture that leverages the latest Smart Edge devices equipped with AI accelerators. This combination capitalizes on recent advancements in CV algorithms, which have become more precise and efficient. The proposed approach centers on utilizing Edge AI devices to autonomously compute parking occupancy.

By utilizing Edge AI Camera devices, the researchers unlock capabilities that were once confined to costly server-side components. These devices now integrate AI and GPU modules capable of executing trillions of operations per second (TOPS). Additionally, support for high-resolution image sensors, along with AI-driven auto-exposure, provides an advanced framework for image capture.

The researchers introduce the concept of constructing 3D models of parking environments using data streams from Edge AI cameras. This innovation enables accurate identification of available on-street parking spaces. By generating 3D bounding boxes around detected vehicles as shown in Figure 8, the researchers enhance tracking precision and address complex parking challenges, including occlusions.

Looking ahead, the researchers emphasize the importance of comprehensive three-dimensional awareness for parking space understanding. They aim to leverage data fusion from GPS and camera attributes, calibrating camera orientation and perspective correction. The goal is to build a robust platform for 3D environment modeling that enhances prediction accuracy.

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**Figure 8.** Stojanović discussed Critical Challenges of Parking Occupancy Detection in Urban Environments

**1.1.5 (Taylor, Ezekiel, & Emmah, 2021)** work revolves around tackling the pressing urban issue of parking space scarcity and its consequential traffic congestion. By leveraging cutting-edge techniques in object detection and predictive modeling, the researcher aims to create impactful solutions for efficient parking management.

The researcher pioneers the utilization of state-of-the-art object detection algorithms in the context of parking management. By harnessing the power of computer vision, these algorithms enable the automatic identification and tracking of vehicles within parking areas.

Through meticulous data collection and analysis, the researcher develops predictive models that anticipate parking space availability. By integrating historical and real-time data, these models provide valuable insights to drivers, aiding them in making informed parking decisions.

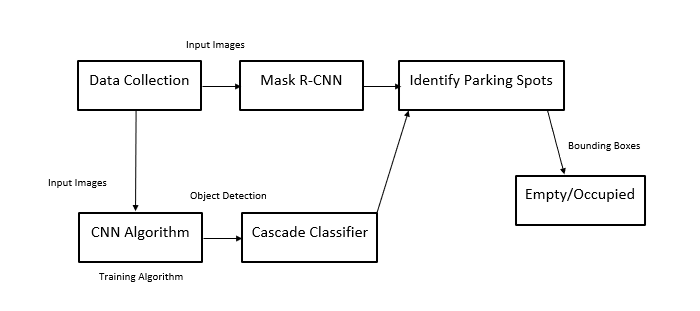
The researcher integrates Internet of Things (IoT) devices and edge computing to enable real-time monitoring of parking occupancy. By deploying IoT sensors and edge devices, the researcher establishes a network that continuously tracks and updates parking availability information and offer significant advantages to urban mobility.

By providing accurate and real-time information on parking availability, the researcher's work aids in reducing traffic congestion resulting from drivers searching for parking spaces.

Efficient parking solutions, driven by the researcher's work, contribute to decreasing carbon emissions caused by unnecessary vehicle circulation in search of parking.

Drivers benefit from data-backed guidance, leading to improved parking experiences and reduced frustration.

The researcher's work not only addresses immediate challenges as shown in Figure 9 but also lays a foundation for future advancements. The findings hold potential for integration into broader smart city initiatives, enhancing overall urban efficiency. Additionally, the research extends its relevance to intelligent traffic management systems, potentially optimizing vehicle flow within urban areas.



**Figure 9.** Taylor exposed Urban Issues of Parking Space Scarcity and its Consequential Traffic Congestion

## Research Gap

* + 1. **Gap Overview**

The research gap evolving nature of parking lot occupancy detection solutions and the imperative to address the complexities of real-world parking scenarios. While recent studies have made significant strides in harnessing deep learning architectures for enhanced accuracy, there's a crucial gap in effectively handling the wide spectrum of diverse and challenging conditions that parking lots present. The current models, while proficient under favorable conditions, demonstrate limitations in adapting to adverse factors like poor lighting, occlusions, and varying weather conditions. This gap indicates the pressing need for research endeavors that prioritize bolstering the resilience and adaptability of these models. Bridging this gap requires innovative strategies that empower models to perform with consistency and accuracy regardless of the visual hindrances encountered. The integration of multi-angle detection strategies, as demonstrated in the research by (Martynova, Kuznetsov, Porvatov et al., 2023), introduces a promising approach. However, a considerable gap exists in the development of a seamlessly integrated system that dynamically selects the appropriate angle for detection based on contextual cues. Efforts to bridge this gap would entail crafting algorithms that not only identify the optimal angle for detection but also transition between angles in real-time to enhance the precision and efficiency of parking detection algorithms.

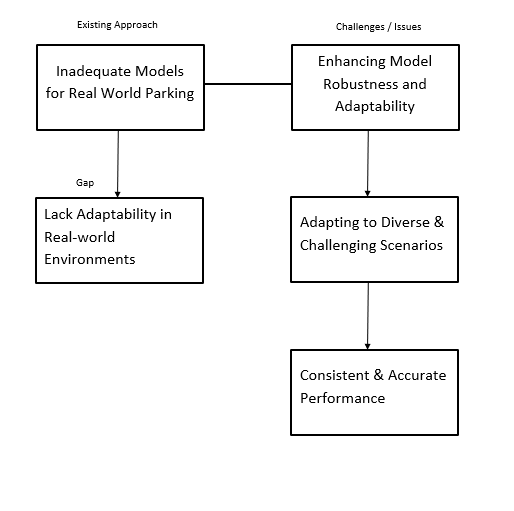
Real-time data processing is another area where the gap demands attention. Urban areas experience rapid fluctuations in parking demand, necessitating swift and accurate data processing and decision-making. The existing algorithms might struggle with processing large volumes of data and making informed decisions promptly. Closing this gap would entail the innovation of advanced algorithms and hardware acceleration techniques capable of processing real-time data efficiently. This enhancement would facilitate timely updates of parking availability information to drivers and stakeholders, contributing to a more responsive and effective parking management system.

Intelligent parking allocation remains a gap in the current research landscape. Beyond mere detection, there is a need to optimize how parking spaces are assigned to improve user experience and alleviate congestion. Addressing this gap involves leveraging machine learning to create allocation algorithms that consider user preferences, proximity to destinations, and available parking types. These algorithms could dynamically assign spaces to optimize overall traffic flow and reduce drivers' search time. This advancement would significantly enhance the efficiency and user-friendliness of urban parking systems.

Lastly, there is a noticeable gap in integrating parking solutions with broader urban planning strategies. While the technical aspects have received considerable attention, seamlessly weaving parking management systems into comprehensive city-wide mobility strategies remains an unexplored territory. Bridging this gap necessitates frameworks that align parking solutions with urban development plans, traffic patterns, and sustainability goals. Such integration could lead to more holistic, effective solutions that address urban mobility challenges in a well-rounded manner. In summary, these research gaps underscore the evolving nature of parking management and the potential for innovative solutions to revolutionize urban mobility.

* + 1. **Diverse and Challenging Parking Lot Scenarios**

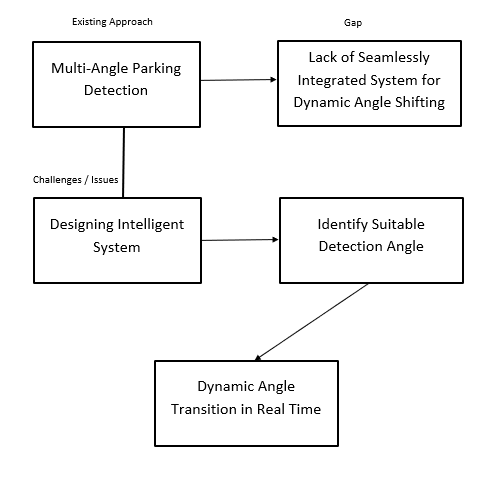
The research conducted by (Marek & Martin, 2021) has significantly advanced the field of parking lot occupancy detection using deep learning models. However, a critical gap persists in effectively addressing the wide spectrum of diverse and challenging parking lot scenarios that are inherent to real-world environments. While these models excel under optimal conditions, they struggle when confronted with poor lighting, occlusions from surrounding objects, and a variety of weather conditions. To bridge this gap, future research needs to delve into the development of models that exhibit enhanced robustness and adaptability. This endeavor aims to ensure consistent and accurate performance irrespective of the complex and unpredictable environmental challenges that may arise. This entails a profound focus on refining models to adeptly handle scenarios of low visibility and effectively differentiate between occupied and unoccupied parking spaces even within the context of challenging visual conditions as shown in Figure 10.



**Figure 10.** Challenges of Parking Lot Scenarios

* + 1. **Integration of Multi-Angle Detection**

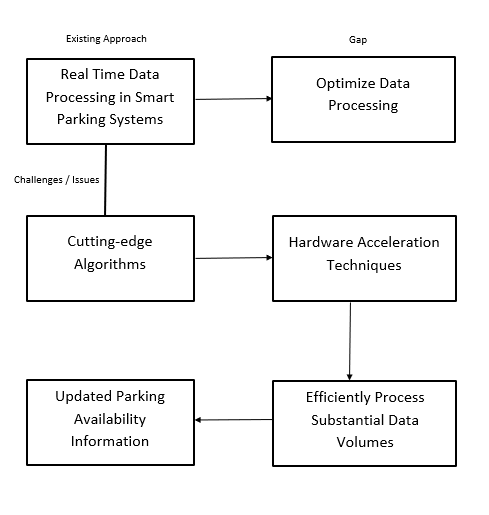
The exploration of multi-angle parking detection, as demonstrated by (Martynova, Kuznetsov, Porvatov et al., 2023), introduces a promising avenue to heighten accuracy by detecting parking spaces from both overhead and low angles. Nonetheless, a gap exists in creating a seamlessly integrated system that can dynamically shift between these different angles based on contextual factors. Pioneering this integration would involve designing an intelligent system that not only identifies the most suitable angle for detection but also fluidly transitions between angles in real-time. This advancement would substantially amplify the efficiency and precision of parking detection algorithms. Successfully bridging this gap mandates the formulation of algorithms that adeptly account for real-time camera positioning, dynamic object tracking, and the capacity to adapt to instantaneous changes within the parking lot environment as shown in Figure 11.



**Figure 11.** Challenges of Multi-Angle Parking Detection

* + 1. **Real-Time Data Processing and Decision-Making**

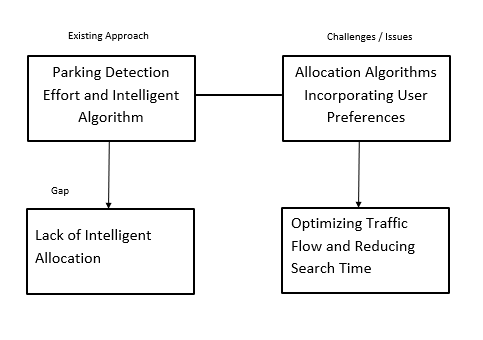
The research conducted by (Sudhakar, Reddy, Mounika et al., 2021) accentuates the vital role of real-time data processing within smart parking management systems. However, a critical gap persists in optimizing the speed and efficacy of data processing as shown in Figure 12, particularly in the face of swift changes in parking demand that urban locales experience. Existing algorithms might face challenges in efficiently managing the substantial influx of data and making swift yet precise decisions. Closing this gap necessitates the development of cutting-edge algorithms and hardware acceleration techniques that can efficiently process substantial data volumes in real-time. This, in turn, facilitates the prompt dissemination of up-to-date parking availability information to both drivers and pertinent stakeholders.



**Figure 12.** Challenges in Real Time Data Processing and Decisoin Making in Parking Systems

* + 1. **Intelligent Parking Allocation**

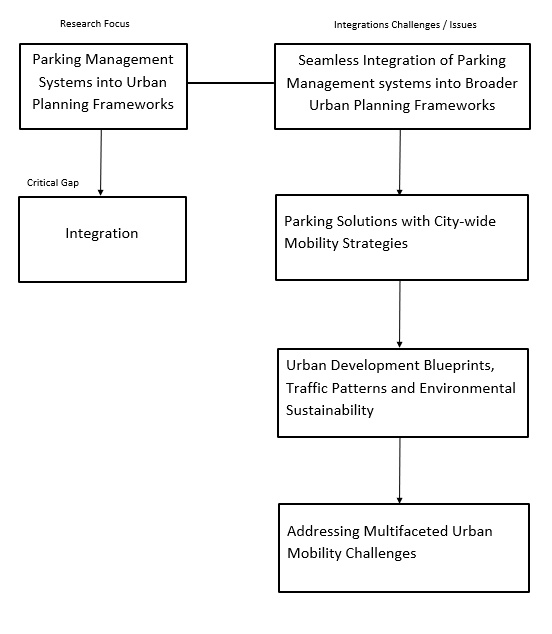
The research conducted by (Taylor, Ezekiel, & Emmah, 2021) has a diverse research effort emphasize parking detection but a gap remains in the development of intelligent algorithms to optimize parking space allocation. Beyond the identification of vacant spaces, optimizing the way these spaces are assigned can tangibly elevate user experiences and alleviate traffic congestion. Attending to this gap involves harnessing the potential of machine learning techniques to devise allocation algorithms that factor in user preferences, proximity to destinations, and the variety of available parking options. These algorithms would dynamically allocate spaces to optimize overall traffic flow and curtail the time drivers expend in search of suitable parking spots. In effect, this strives to make urban parking systems not only more efficient but also remarkably user centric as shown in Figure 13.



**Figure 13.** Challenges in Dynamic Parking Allocation

* + 1. **Integration with Urban Planning**

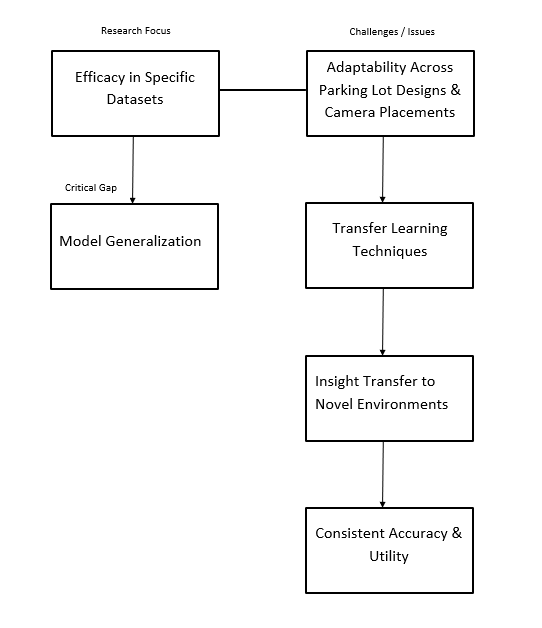
While research predominantly focuses on the technical dimensions, a critical gap emerges in seamlessly integrating parking management systems into broader urban planning frameworks. As illuminated by the works of (Martynova, Kuznetsov, Porvatov et al., 2023), these systems wield substantial influence over traffic management, transportation policies, and the overall urban experience. As shown in Figure 14, bridging this gap necessitates the development of frameworks that seamlessly amalgamate parking solutions with city-wide mobility strategies. This integration should account for various facets, including urban development blueprints, traffic patterns, and environmental sustainability aspirations. This holistic integration has the potential to engender more comprehensive, effective solutions that holistically address the multifaceted challenges of urban mobility.



**Figure 14.** Challenges of Integration with Urban Planning

* + 1. **Generalization and Adaptation to Various Environments**

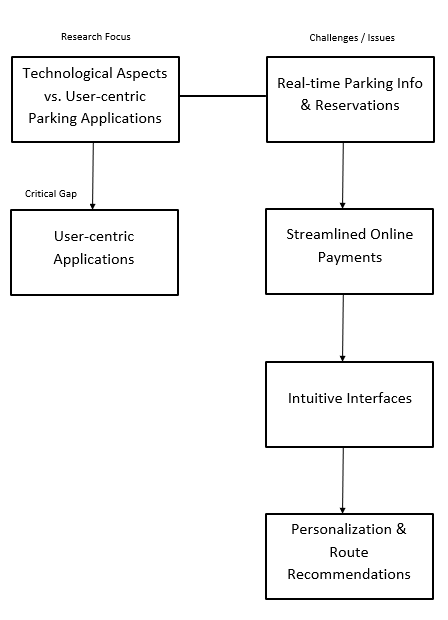
The research by (Marek & Martin, 2021) presents the efficacy of models within specific datasets. However, a significant gap prevails in achieving model generalization across diverse parking lots and urban contexts. Given the wide-ranging variations in parking lot designs and camera placements, models must exhibit adaptability without necessitating extensive retraining. To surmount this gap, which is shown in Figure 15, researchers should delve into the realm of transfer learning techniques that empower models to glean insights from one parking lot and subsequently apply that knowledge to novel environments. This novel approach facilitates models in maintaining consistent accuracy and utility across a spectrum of parking lot scenarios.



**Figure 15.** Challenges of Model Generalization across Diverse Parking Lots

* + 1. **User-Centric Applications**

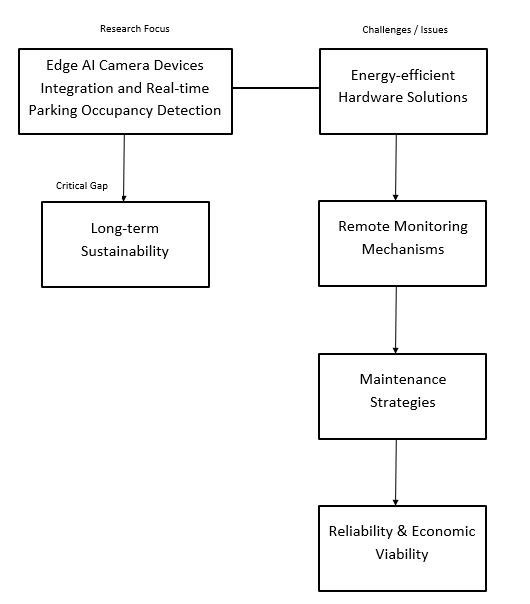
Amidst the technological focus of some research endeavors, a gap emerges in crafting user-centric applications that seamlessly interface with parking management systems. As underscored by (Sudhakar, Reddy, Mounika et al., 2021) and (Taylor, Ezekiel, & Emmah, 2021), user-friendly mobile applications wield the potential to provide real-time parking information, enable reservations, and streamline online payments. As shown in Figure 16, bridging this gap entails conceiving intuitive interfaces that furnish drivers with pertinent, actionable parking information. Furthermore, future research could delve into avenues for personalizing user experiences. This could encompass functionalities like suggesting preferred parking spots or furnishing tailored route recommendations towards available parking spaces.



**Figure 16.** Challenges of Crafting User-Centric Applications with Parking Management Systems

* + 1. **Long-Term System Sustainability**

The integration of Edge AI camera devices, as explored by (Stojanović, Damjanović, Vukmirović et al., 2021), has unveiled the realm of real-time parking occupancy detection. However, a gap endures in addressing the long-term sustainability of such systems. Given the perpetual operation of these devices, factors such as maintenance, energy efficiency, and scalability are of paramount significance. To attend to this gap, it becomes imperative to conceive energy-efficient hardware solutions, implement remote monitoring mechanisms, and outline maintenance strategies that secure the longevity and cost-effectiveness of smart parking systems. This focus on sustainability serves as a linchpin in upholding the reliability and economic viability of these systems over extended durations as shown in Figure 17.



**Figure 17.** Challenges of Long-Term System Sustainability in Parking Systems

## Problem Statement

The growing challenges of parking management in urban areas have become a significant concern due to the escalating number of vehicles and limited parking spaces. Current parking detection methods exhibit limitations in accurately identifying parking spaces, particularly under adverse conditions such as poor lighting, occlusions, and varied viewpoints. This research endeavors to tackle these issues by proposing an innovative approach to parking space detection. The core problem revolves around developing a robust and adaptable parking detection system that can effectively operate under diverse environmental conditions, encompassing overhead and low-angle views. The objective is to advance the accuracy and efficiency of parking detection, ultimately contributing to the optimization of urban mobility, alleviation of traffic congestion, and enhancement of overall parking management effectiveness.

## Research Questions

**1.5.1** How can deep learning architectures be leveraged to enhance the accuracy and efficiency of parking lot occupancy detection in challenging visual conditions like poor lighting, occlusions, and various weather conditions?

**1.5.2** What are the strengths and weaknesses of different state-of-the-art deep learning architectures, including vision transformers and convolutional neural networks, in the context of parking lot occupancy detection, and how can these insights guide the selection of an optimal architecture for the proposed algorithm?

**1.5.3** How do the integrated image processing, IoT technology, and cloud-based solutions contribute to the effectiveness and user-friendliness of the Smart Parking Management System, and how do these components collectively address the challenges of parking space availability in urban areas?

**1.5.4** How slot allocation will be improved by using the client application?

## Research Objectives

**1.6.1** The research aims to leverage deep learning architectures for more accurate parking lot occupancy detection in challenging visual conditions. Through model exploration, empirical evaluation, and parameter optimization, the goal is to enhance real-world parking space detection systems and improve urban mobility.

**1.6.2** The research aims to assess the strengths and weaknesses of vision transformers and convolutional neural networks (CNNs) in parking lot occupancy detection. By comparing their performance in diverse visual conditions, the study aims to guide the selection of an optimal architecture for improved accuracy and efficiency in detecting parking space occupancy.

**1.6.3** This research examines the integration of image processing, IoT technology, and cloud-based solutions in the Smart Parking Management System. It evaluates their collective impact on effectiveness, user-friendliness, and addressing urban parking challenges. The study aims to uncover how these components synergize to optimize parking management and enhance urban mobility solutions.

**1.6.4** This research examines how a client application improves slot allocation in parking management systems. It analyzes the application's functionalities, quantifies its impact on efficiency and user satisfaction, and investigates its technological mechanisms for data-driven decision-making and dynamic allocation processes.

## Research Contributions

* + 1. **Background of Research**

The research addresses the increasingly pressing issue of parking space scarcity in urban areas. As the global number of vehicles continues to rise, the problem of parking occupancy has become a significant concern, and this challenge is predicted to intensify in the coming years. While this topic has garnered scientific attention over time, a satisfactory solution has remained elusive. Various methods have been explored, including the use of hardware sensors for individual parking spaces, as well as the application of Computer Vision (CV) technology to tackle the problem.

The recent advancements in CV have significantly improved the precision of algorithms. These improvements have been accompanied by the development of smaller data models, facilitating real-time detection on Edge AI-capable devices. Notably, Edge AI Cameras have emerged as a game-changing solution. These devices now boast performance capabilities comparable to high-cost server-side components. Equipped with AI and GPU modules capable of processing trillions of operations per second (TOPS), Edge AI Cameras also support image sensors with resolutions reaching up to 200 Megapixels. This technological landscape lays the foundation for a platform capable of capturing 3D models of urban environments, powered by the latest Edge AI camera devices.

The research particularly focuses on the parking challenges faced in Pakistan due to the exponential increase in the number of vehicles. In this context, there is a lack of adequate parking management systems, especially concerning deterministic closed parking scenarios. Deterministic closed parking is extensively adopted in areas such as malls, hospitals, and residential complexes, driven by security and environmental considerations. However, challenges persist, including sensor costs, efficient penalty administration, and optimized slot allocation.

The primary contribution of this research lies in its proposal of a comprehensive solution that combines image processing techniques with a goal-oriented agent for predicting parking occupancy in closed deterministic environments. A pivotal component of this solution is the integration of a mobile application, enabling users to seamlessly manage various parking operations. This application acts as a vital interface for collecting data from the parking manager and facilitating user engagement.

The technical aspects of the research can be summarized as follows.

**Object Detection**

The research's initial phase involves the detection of objects as they enter the parking area. Surveillance cameras capture images of incoming vehicles and extract license plate characters. Through image processing techniques, such as Optical Character Recognition (OCR) or specialized license plate recognition (LPR), the system identifies the type of vehicle. The utilization of third-party databases enhances vehicle type recognition, bolstering security measures. For previously verified vehicles, local databases expedite the process, reducing server-side requests and minimizing delays. Vehicle and owner information is relayed to the Parking Manager Agent for cost and duration management.

**Parking Occupancy Detection or Prediction**

Central to the research's focus is the challenge of detecting parking space occupancy. Surveillance cameras capture real-time images of parking spaces as vehicles enter designated slots. These images are transmitted to the Parking Manager Agent, responsible for distinguishing between occupied and unoccupied spaces. Users, aided by the mobile application, receive this information, and are required to select a parking slot within a specified timeframe. If no selection is made, the Parking Manager Agent autonomously allocates a slot. The mobile application guides users to their selected parking slot using map-based directions, while LED indicators provide real-time visibility into slot availability.

* + 1. **Issues, Problems and Challenges**

In essence, the research contribution endeavors to revolutionize parking management by integrating cutting-edge technology, user-centric mobile applications, and sophisticated data processing techniques. By comprehensively addressing challenges, optimizing slot allocation, and harnessing the potential of Edge AI, the research aims to create a transformative solution that enhances urban mobility, mitigates traffic congestion, and ultimately improves the overall quality of life.

The research aims to tackle the pressing issue of parking space shortage in urban areas, exacerbated by the increasing number of vehicles. The study proposes a comprehensive solution with a specific focus on closed deterministic parking scenarios, a domain where existing research often lacks in the integration of object detection techniques. Additionally, previous studies have faced challenges related to illumination factors and recurring issues such as incorrect parking, crossing allocated slots, and inefficiencies in cost management.

The research project unfolds through various phases, each contributing significantly to the overarching solution. It centers on deterministic environments like malls, hospitals, and residential areas, addressing the need for tailored solutions to ensure security and accommodate environmental considerations. By targeting enclosed parking spaces, the research bypasses challenges associated with illumination commonly found in open parking scenarios, thereby enabling more effective control over lighting conditions.

A noteworthy innovation lies in the utilization of license plate recognition for object detection. As vehicles enter the parking area, surveillance cameras capture license plate images, and advanced image processing techniques are applied to extract characters, enhancing security protocols, and streamlining entry processes. The integration of third-party APIs or databases further bolsters authentication efforts by classifying vehicle types and validating information, thereby creating a robust system.

The research emphasizes meticulous record-keeping of both vehicles and their owners, a crucial aspect for penalty administration, efficient parking fee management, and regulatory compliance. By opting for a local server approach over cloud-based solutions, the project enhances data security, reduces latency, and improves system responsiveness. A user-friendly mobile application becomes a pivotal platform for users to seamlessly manage various parking-related tasks, including selecting slots, receiving notifications, and accessing fee and duration information.

Efficient parking duration management is introduced to ensure accurate fee calculations and reduce the likelihood of parking violations. The dynamic allocation and reallocation of parking slots through the mobile application optimizes slot usage and availability. Surveillance cameras play a key role in capturing real-time parking space and vehicle images, thereby facilitating the entire parking management process. Effective notification mechanisms are also integrated to inform users about slot availability, allocated time limits, and penalties for violations.

In essence, this research project's contributions stem from its holistic approach to addressing limitations seen in previous studies. By harnessing advanced image processing techniques and embracing innovative technologies, the study aims to reshape car parking management. This entails enhancing efficiency, user experience, and urban mobility, all while mitigating congestion and minimizing the environmental impact associated with parking challenges.

**Research Modules**

The research methodology is delineated into several distinct and cohesive modules, each playing a pivotal role in realizing the comprehensive solution. These modules collectively contribute to addressing the challenges associated with parking occupancy prediction, object detection, and efficient parking management.

**Module 1 (Object Detection)**

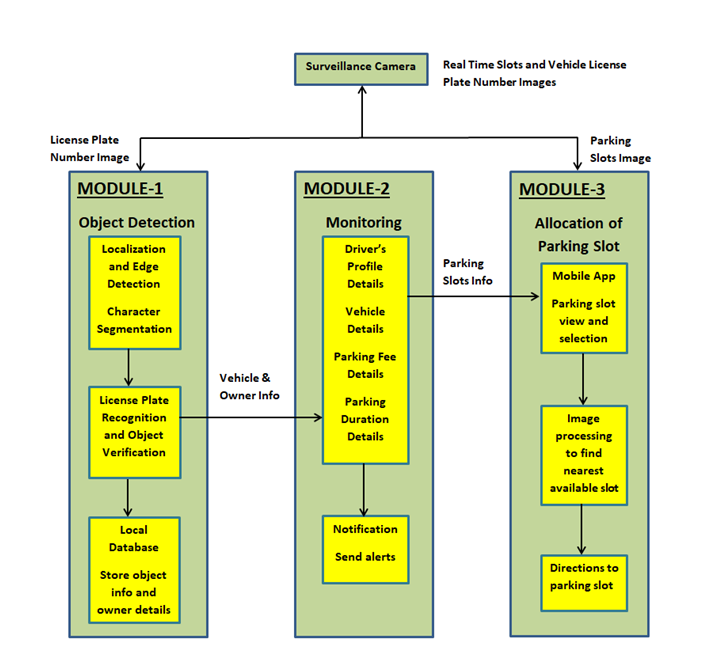
The first module, termed "Object Detection," constitutes the initial phase of the research. Its primary objective is to discern and classify incoming vehicles, with a specific focus on identifying cars. As vehicles enter the parking area, specialized surveillance cameras capture images of their license plates. These images are then forwarded to a local server for meticulous analysis. The server employs intricate image processing techniques to discern and localize edges within the images. Subsequently, through character segmentation and the utilization of a third-party database or API linked to government departments, the system accurately extracts and interprets the license plate numbers. This approach enables the system to categorize vehicles and ascertain their ownership details. Notably, verified data is judiciously stored in a local database, which expedites subsequent entry procedures and streamlines record-keeping for the enforcement of penalties and regulations.

**Module 2 (Monitoring)**

The subsequent module, "Monitoring," constitutes the crux of the project and involves the role of the Parking Manager. Within this phase, the Parking Manager assumes multifaceted responsibilities critical to effective parking management. Firstly, it keeps a comprehensive record of car owners, thereby maintaining a detailed profile of each driver. This profile encompasses crucial details such as the driver's name, CNIC number, mobile number, and address. These details are extracted from the license plate number during the object detection phase. Secondly, the Parking Manager adeptly manages vehicle-related information, including the license plate number, car model, and engine number. This information is systematically obtained from surveillance cameras positioned at parking entrances, which capture data during the object detection process. Thirdly, the Parking Manager diligently maintains a record of parking fees, allowing for customizable fee structures, such as hourly charges. Moreover, it meticulously tracks the duration of each vehicle's stay within the parking premises, effectively ensuring adherence to parking regulations. Lastly, the Parking Manager assumes the responsibility of monitoring parking slot availability. This is achieved through the consistent capture of parking slot images by surveillance cameras, which are then relayed to the manager for real-time updates on slot occupancy status.

**Module 3 (Allocation of Parking Slot)**

The final module, "Allocation of Parking Slot," introduces an interactive and user-centric approach to parking slot allocation. Users initiate requests for parking slots through a dedicated mobile application. The application provides an intuitive interface that displays available slots in a green color and occupied slots in red. Users are afforded a designated time window to select a preferred parking slot. In the event that users fail to make a selection within the stipulated time, the Parking Manager intervenes by autonomously allocating a suitable parking slot based on proximity. Surveillance cameras play a pivotal role in this process, capturing and transmitting images to the Parking Manager for verification. Subsequently, the system guides users to their designated parking slots through the mobile application, employing navigational-like instructions that enhance user experience and facilitate smooth parking.



The system incorporates mechanisms to address scenarios where users inadvertently or deliberately vacate their allocated parking slots. Notifications are triggered to initiate slot reallocation or to provide users with guidance for their next steps. If parking slots are available, the Parking Manager efficiently reallocates the nearest available slot and notifies the user. Conversely, if no slots remain unoccupied, users are prompted to exit the parking area and initiate a fresh entry.

The culmination of these modules results in a comprehensive system architecture that seamlessly integrates object detection, agent monitoring, and parking slot allocation. Notably, the implementation of advanced image processing techniques, coupled with a local server-based approach and an intuitive mobile application, collectively represents a significant leap in car parking management. This research methodology addresses the limitations identified in prior studies, offering innovative solutions for parking occupancy prediction, meticulous record-keeping, and the judicious utilization of parking spaces. The incorporation of technologies such as Python, Keras, TensorFlow, and GPU resources further amplifies the project's potential for efficient and effective implementation.

# **Literature Review**

## 2.1 Revising Deep Learning Methods in Parking Lot Occupancy Detection

Parking lot occupancy detection is a crucial aspect of smart city development, aiming to enhance urban mobility and alleviate traffic congestion. Over time, researchers have explored various algorithms to achieve accurate and efficient detection of available parking spaces, with a recent focus on computer vision techniques, particularly those based on neural networks. Classical approaches heavily relied on handcrafted features and traditional machine learning methods, utilizing image processing, edge detection, and template matching. However, their limited adaptability to diverse real-world visual conditions led to the emergence of deep learning-based methods.

Convolutional Neural Networks (CNNs) revolutionized the field, showing significant improvements over classical approaches in parking lot occupancy detection. Various CNN architectures, such as VGG, ResNet, and MobileNet, have been employed for feature extraction and image classification tasks in this domain. Despite these advancements, challenges persist in terms of generalization, as many deep learning models lack robustness when facing diverse visual conditions not represented in their training datasets.

Recently, Vision Transformers (ViTs) have emerged as a promising architecture to address the generalization issue. By utilizing self-attention mechanisms, ViTs capture global context and long-range dependencies in images, making them more adaptable to varying visual conditions. This ability has shown promise in enhancing parking space detection across different environments (Martynova, Kuznetsov, Porvatov, & Tishin, 2023).

The importance of diverse and large-scale datasets has been highlighted in the literature, as they play a crucial role in training and evaluating parking lot occupancy detection models. Existing datasets, such as PKLot, ACMPS, CNRPark, and ACPDS, have been valuable for benchmarking purposes. However, they often lack comprehensive representation of real-world visual variations like winter weather, glare, fog, and diverse occlusions. To address this limitation, recent efforts have introduced datasets like SPKL, encompassing a broader range of visual conditions. The availability of diverse datasets enables a more comprehensive evaluation of algorithms and fosters the development of robust models.

In conclusion, parking lot occupancy detection algorithms have evolved from classical methods to deep learning-based approaches, and more recently, the exploration of Vision Transformers. While deep learning has shown remarkable progress, challenges related to generalization persist. Addressing these challenges and emphasizing diverse datasets for evaluation will be critical in developing accurate and adaptable parking lot occupancy detection algorithms, contributing significantly to smart city initiatives by improving urban mobility and traffic management.

Image preprocessing plays a vital role in training machine learning models, especially in computer vision tasks. One common technique is data augmentation, which involves generating altered versions of input images to provide more diverse training data without the need for additional labeling efforts. Augmentation techniques include image flipping, random cropping, translation, rotation, and noise injection (Nanni et al., 2021; Shorten and Khoshgoftaar, 2019). These operations help prevent models from memorizing specific pixel arrangements and promote generalization, thus enhancing the robustness of parking lot occupancy detection algorithms.

Patch-based methods constitute a prevalent approach in parking lot occupancy detection. These methods involve cropping specific regions from the input image, typically corresponding to individual parking lots, and applying binary classifiers to determine occupancy status. Various convolutional neural network (CNN) architectures have been explored in this context, such as AlexNet, mAlexNet, CarNet, VGG, ResNet, and EfficientNet (Krizhevsky et al., 2012; Amato et al., 2016; Nurullayev and Lee, 2019; Simonyan and Zisserman, 2015; He et al., 2016; Tan and Le, 2019). Each architecture offers unique features and depths, with EfficientNet and vision transformers showing promise in achieving competitive performance (Ha et al., 2020; Shah et al., 2022; Wang et al., 2022).

EfficientNet, developed through neural architecture search, employs a scaling method to uniformly adjust depth, width, and resolution using a compound coefficient. This approach demonstrates remarkable generalization ability, suggesting its potential for efficient parking lot occupancy detection systems.

On the other hand, intersection-based methods take a different approach, relying on object detection models as the initial step in the classification pipeline. Examples of such models include Faster R-CNN and RetinaNet (Ren et al., 2015; Lin et al., 2017). These models detect vehicle bounding boxes and assess parking lot occupancy based on the intersection area between the detected vehicles and parking spaces, using a predefined threshold.

Faster R-CNN, a classic two-stage detection algorithm, utilizes a region proposal network to simplify the generation of object proposals. On the other hand, RetinaNet is a one-stage object detection model that employs a focal loss function to handle imbalanced samples effectively. Both approaches show promise in improving parking lot occupancy detection, but they are currently underrepresented compared to patch-based methods.

In conclusion, this literature review provides valuable insights into deep learning methods for parking lot occupancy detection. Patch-based approaches using CNN architectures like AlexNet, VGG, and EfficientNet have been extensively studied and applied. Intersection-based methods, represented by Faster R-CNN and RetinaNet, show potential but require further exploration. Future research can focus on investigating the efficacy of vision transformers and exploring intersection-based techniques to improve the accuracy and efficiency of parking lot occupancy detection systems in various real-world applications. Continued advancements in these methods will contribute to more effective parking management solutions, benefiting urban planning, traffic flow, and overall transportation efficiency.

## 2.2 Image-Based Parking Space Occupancy Classification

(Marek & Martin, 2021) presents a comprehensive study on image-based parking space occupancy classification. The primary focus of this research is to introduce a new dataset, Action-Camera Parking Dataset (ACPDS), specifically designed to improve and accurately test model performance on previously unseen parking lots. The need for such datasets arises due to the growing importance of real-time parking space occupancy information in optimizing traffic flow, reducing congestion, emissions, and enhancing overall efficiency in urban parking management.

The paper begins by discussing the two common approaches to monitor parking space occupancy installing sensors on each parking space or using cameras to monitor multiple spaces simultaneously. Camera-based approaches offer cost advantages, and for this study, the authors focus solely on image-based models. They elaborate on the benefits of capturing images rather than live videos, such as better color reproduction in low-light conditions, reduced data flow, and immediate recovery from camera feed failures. Moreover, images are easier to capture and annotate, which is crucial in building a robust dataset.

The authors then delve into existing works on camera-based parking space occupancy classification, which generally rely on large but generic object-detection datasets or limited application-specific datasets for training. These models are evaluated on separate datasets containing unseen parking lots to assess model generalization. The paper highlights the limitation of not directly testing model generalization using separate parking lots, which makes it difficult to determine the true accuracy of the models.

To address these limitations, the researchers introduce the ACPDS dataset. They emphasize its uniqueness, with each image captured from a unique view and systematically annotated using precise quadrilateral annotations for each parking space. The dataset contains over 11,000 unique parking space annotations across various parking lots and streets, and each set (train, validation, and test) consists of separate parking lots, ensuring accurate assessment of model generalization. The authors believe this dataset will facilitate better model development and benchmarking, leading to improvements in parking space occupancy classification.

Next, the paper proposes two custom models for parking space occupancy classification based on the R-CNN and Faster R-CNN FPN architectures. Both models are inspired by two-stage object detectors, and their designs leverage the precise parking space annotations in ACPDS. The R-CNN-based model uses image patches directly pooled from the image, followed by binary classification using a ResNet50 backbone. In contrast, the Faster R-CNN FPN-based model employs a feature pyramid network to pool features corresponding to each parking space and subsequently classifies them using a classification head.

The annotation process for ACPDS involves labeling each parking space with a quadrilateral, aligned with the edges of the parking space. The authors describe the challenges faced during annotation, particularly when dealing with occlusions and limited visibility of parking spaces. Despite these challenges, the authors ensured that each annotation was carefully validated to provide precise and reliable data for model training and evaluation.

The dataset's size and diversity are highlighted, with 293 images containing over 11,000 unique parking space views across different parking lots and streets. The authors emphasize that the dataset includes both occupied and unoccupied parking spaces and exhibits varied weather and lighting conditions, making it a challenging and realistic dataset for parking space occupancy classification.

The paper then presents the training details for the proposed models, including hyperparameter configurations, optimization algorithms, and data augmentation techniques. The models are trained on the ACPDS dataset with different resolutions, and the authors compare their performance based on validation accuracy. They identify the most suitable configurations and discuss the models' inference times, which are crucial for real-world deployment.

Finally, the research concludes by emphasizing the practicality of their R-CNN-based model for real-world deployment due to its flexibility in handling different input resolutions. The authors acknowledge the limitations and challenges in their dataset and encourage researchers to utilize ACPDS for benchmarking and further improvements in parking space occupancy classification research.

In conclusion, this research paper presents a well-structured and detailed study on image-based parking space occupancy classification. By introducing the ACPDS dataset and proposing custom models, the authors aim to enhance the field's progress and contribute to more efficient parking management systems and improved driver navigation in urban areas.

Parking occupancy detection is a critical component in managing urban traffic and parking systems [Acharya et al., 2018]. Deep learning methods have shown great promise in this domain due to their ability to process complex visual data efficiently [Amato et al., 2017]. Acharya et al. [2018] proposed a real-time image-based parking occupancy detection system using deep learning. They utilized a convolutional neural network (CNN) architecture for accurate and efficient parking slot occupancy detection.

In decentralized parking environments, it is crucial to have a reliable parking lot occupancy detection system to manage parking space efficiently [Amato et al., 2017]. Amato et al. [2017] presented a deep learning-based approach for decentralized parking lot occupancy detection. They employed deep learning techniques to analyze data from multiple parking lots and achieved promising results.

Real-time tracking is another essential component in parking occupancy detection systems [Bewley et al., 2016]. Bewley et al. [2016] proposed a simple online and real-time tracking method suitable for various applications, including parking lot surveillance. Their method can efficiently track objects in real-time, making it suitable for parking occupancy detection systems.

Video-based parking measurement systems are gaining popularity due to their accuracy and real-time capabilities [Cai et al., 2019]. Cai et al. [2019] developed a deep learning-based video system for accurate and real-time parking measurement. Their system utilized deep learning algorithms to process video data and achieve precise parking measurements in real-time.

Transformers have shown significant advancements in various computer vision tasks, including object detection [Carion et al., 2020]. Carion et al. [2020] introduced an end-to-end object detection approach with transformers. This method achieved state-of-the-art results in object detection tasks, which can be potentially applied to parking slot detection and occupancy estimation.

To address the need for robust datasets in parking lot classification, Almeida et al. [2015] introduced the PKLot dataset. The PKLot dataset is a robust dataset specifically designed for parking lot classification and has been widely used for training and evaluating parking occupancy detection models.

Large-scale hierarchical image databases like ImageNet have been instrumental in advancing deep learning models for various visual recognition tasks [Deng et al., 2009]. ImageNet provides a vast collection of labeled images, which has been valuable in training deep learning models for object detection and classification.

Feature pyramid networks (FPN) have been employed to enhance object detection accuracy by capturing multi-scale features [Lin et al., 2017]. FPN architecture has been successfully integrated with various object detection systems and can be utilized to improve the performance of parking occupancy detection models [Lin et al., 2017].

In low-light conditions, burst photography techniques have been employed to capture high dynamic range images [Hasinoff et al., 2016]. These techniques can be applied in parking surveillance to improve visibility and enhance the accuracy of parking occupancy detection systems.

Mask R-CNN is a popular framework that integrates object detection with instance segmentation [He et al., 2020]. It can accurately detect objects and classify them into specific categories. Mask R-CNN has been employed in various computer vision applications and has the potential to enhance parking occupancy detection systems.

Deep residual learning, introduced by He et al. [2016], has significantly improved the performance of deep neural networks in image recognition tasks. It allows training deeper networks and has been instrumental in advancing the capabilities of object detection models.

Drone-based object counting using spatially regularized regional proposal networks has shown promise in counting objects efficiently [Hsieh et al., 2017]. This approach can be adapted to count occupied parking spaces from aerial footage, providing valuable information for parking occupancy detection.

Edge artificial intelligence on IoT devices has been explored to build smart, efficient, and reliable parking surveillance systems [Ke et al., 2020]. Ke et al. [2020] presented a parking surveillance system that incorporates edge AI for real-time processing of parking data, making it suitable for IoT-based parking occupancy detection systems.

Vision-based parking-slot detection is a crucial step in parking occupancy detection systems [Li et al., 2017]. Li et al. [2017] proposed a learning-based approach for vision-based parking-slot detection. Their approach uses deep learning techniques to accurately detect parking slots from images, contributing to effective parking occupancy estimation.

The regularization effect of the initial large learning rate in training neural networks has been investigated [Li et al., 2019]. Understanding this effect is vital for optimizing the training process and improving the performance of parking occupancy detection models.

Decoupled weight decay regularization is a technique used to enhance the generalization ability of deep learning models [Loshchilov et al., 2019]. This technique can be applied in training parking occupancy detection models to improve their performance and robustness.

PyTorch is a widely used deep learning library that provides an imperative programming style, making it easy to work with and experiment with various deep learning models [Paszke et al., 2019]. PyTorch has been widely used in developing deep learning models for computer vision tasks, including parking occupancy detection.

Faster R-CNN is a popular object detection framework that incorporates region proposal networks for faster and more accurate object detection [Ren et al., 2017]. Faster R-CNN has been successfully employed in various object detection applications and can contribute to enhancing the efficiency of parking occupancy detection systems.

## 2.3 Parking Occupancy Prediction using (CV) with Location Awareness

The escalating growth in the number of vehicles on the roads has led to a pressing need for efficient parking management systems. Traditional parking methods often lead to challenges in finding available parking spaces, causing congestion, increased fuel consumption, and environmental pollution. To tackle these issues, researchers have introduced the concept of Smart Parking Systems, which leverage cutting-edge technologies to optimize parking space utilization and enhance user experience.

Smart Parking Systems encompass a wide range of solutions, and one of the central components is the development of a mobile application. This application serves as a user-friendly interface, providing real-time information about available parking spaces, allowing users to pre-book slots, and guiding them to the nearest parking lots. With the help of these applications, users can efficiently locate parking spaces, reducing the time spent searching for parking and easing traffic congestion (Amato et al., 2016).

An essential feature of Smart Parking Systems is the use of Image Processing techniques to identify vehicle registration plates. These techniques, integrated with sensors and cameras, facilitate the automatic opening and closing of parking lot gates whenever a vehicle approaches the entrance. This automation not only streamlines the entry and exit process but also enhances security by preventing unauthorized access (Nieto et al., 2018).

To detect the availability of parking spaces, Smart Parking Systems incorporate various hardware components, such as Reflective Type Infrared Proximity Sensors. These sensors can accurately identify whether a parking slot is occupied or vacant, enabling real-time updates about parking space availability. The integration of such sensors with the mobile application ensures that users are provided with up-to-date information, allowing them to make informed decisions about where to park (Ng et al., 2018).

Additionally, the utilization of the Internet of Things (IOT) technology plays a significant role in the functionality of Smart Parking Systems. IOT enables the seamless connectivity of hardware components, allowing data to be collected and transmitted in real-time. This connectivity not only facilitates efficient parking management but also enables remote monitoring and control of the parking infrastructure (Ke et al., 2020).

The data collected by Smart Parking Systems is stored in the cloud, providing a centralized platform for managing parking-related information. The cloud integration enables seamless billing processes and allows users to make payments through the mobile application. Moreover, with the data stored in the cloud, Smart Parking Systems can analyze parking patterns, optimize parking space allocation, and generate insights for improving overall parking management (Padmasiri et al., 2020).

The future of Smart Parking Systems is promising, with potential enhancements in Artificial Intelligence and Machine Learning. Integrating these technologies can further improve vehicle identification, leading to better security measures and fraud prevention. Moreover, the accumulated data in the cloud can be leveraged to provide personalized parking recommendations to users, tailoring the parking experience to individual needs (Xiang et al., 2017; Luo et al., 2018).

In conclusion, Smart Parking Systems offer an innovative solution to the challenges posed by urban parking. By leveraging advanced technologies such as Image Processing, IOT, and mobile applications, these systems enhance parking space utilization, reduce traffic congestion, and improve the overall user experience. The continuous development and integration of new technologies holds the potential to make Smart Parking Systems an indispensable part of smart city initiatives and significantly transform urban transportation.

Moving on to the related work in the field of parking occupancy prediction using computer vision with location awareness, several research papers have made notable contributions.

Amato et al. (2016) proposed an approach using Convolutional Neural Networks (CNNs) onboard a Raspberry Pi camera to classify parking spaces as free or occupied. The experiment used two data sets PKLot and CNRPark, with the latter being more challenging due to occluded parking spaces. The CNN model, mAlexNet, achieved better results than LeNet-5 (mLeNet) and other state-of-the-art models.

In Nurullayev and Lee's work (2019), a novel Dilated Convolutional Neural Network named CarNet was introduced for parking occupancy detection. Dilation was employed to increase the global view of the network while keeping the parameters increase linearly. The experiments showed that CarNet with dilation outperformed CarNet without dilation and achieved better results than mAlexNet when tested on PKLot and CNRPark data sets.

Nieto et al. (2018) proposed a multi-camera system that combines the results of individual cameras to create a final multi-camera spot matrix representing the occupation of the parking lot. Two algorithms, Faster Region-Based Convolutional Neural Network (R-CNN) and Deformable Parts Model (DPM), were used for vehicle detection. Perspective correction significantly improved detection accuracy.

Ke et al. (2020) presented a system for parking occupancy detection using real-time video feed. The system achieved an overall detection accuracy of 95.6% for various scenarios, including indoor, outdoor, rainy, sunny, foggy, daytime, and nighttime situations.

Padmasiri et al. (2020) introduced a parking detection system that guides drivers to parking spaces. It employed RetinaNet and Fast R-CNN for detecting occupied and available parking spaces. The evaluation showed consistent higher precision for occupied data, indicating the effectiveness of the models.

Ng et al. (2018) used two lightweight convolutional neural networks, baseline and minimal MobileNet, for parking space classification. Minimal MobileNet outperformed baseline MobileNet, providing the same detection accuracy at a much higher speed.

Finally, Xiang et al. (2017) developed a real-time parking occupancy detection method based on Haar-AdaBoosting and convolutional neural networks. The proposed system achieved an accuracy rate not lower than 94% and demonstrated stable detection accuracy even during nighttime with stable illumination.

In summary, the research papers discussed above have contributed to the advancement of parking occupancy prediction using computer vision and location awareness. These works showcase the potential of using deep learning models and multi-camera systems to address parking-related challenges and improve parking space management.

Parking occupancy prediction is a crucial challenge in urban environments due to the ever-increasing number of vehicles. Conventional methods utilizing hardware sensors for parking space detection have shown limited success. However, recent advances in Computer Vision (CV) algorithms, along with powerful Edge AI-capable devices, offer the potential for more precise and real-time solutions. In a study proposing car parking occupancy detection using smart camera networks and deep learning (Amato et al., 2016), Convolutional Neural Networks (CNNs) onboard Raspberry Pi cameras were utilized to classify parking spaces. The authors found that mAlexNet outperformed other models, showcasing robustness to noise and challenging scenarios.

The PKLot dataset (De Almeida et al., 2015) is a widely used resource for parking occupancy prediction. It contains numerous parking lot images with annotations for occupied and vacant spaces, serving as a valuable training and testing dataset for various parking occupancy detection algorithms. Furthermore, a Dilated Convolutional Neural Network named CarNet (Nurullayev & Lee, 2019) was introduced to perform generalized parking occupancy analysis. The use of dilation allowed the network to capture a more extensive global view of the parking area, resulting in improved accuracy compared to traditional methods like mAlexNet.

A multi-camera system for parking occupancy prediction was proposed by Nieto et al. (2018), where parallel processing of each camera was combined to create a final parking spot occupation matrix. The system utilized Faster Region-Based Convolutional Neural Network (R-CNN) and Deformable Parts Model (DPM) algorithms for vehicle detection. In a study by Ke et al. (2020), a smart and efficient parking surveillance system based on real-time video feed from camera nodes and IoT devices was introduced. This system achieved an overall detection accuracy of 95.6% for various environmental scenarios using Mobilenet Single-Shot Detection (SSD) and Background-Based Detection algorithms.

Additionally, the study conducted by Ng et al. (2018) explored two lightweight convolutional neural networks, baseline, and minimal MobileNet, for parking space classification. The minimal MobileNet with fewer parameters and smaller input resolution exhibited better performance, achieving 99% precision during testing, making it ideal for parking occupancy detection on embedded devices. Finally, Xiang et al. (2017) presented a novel method for real-time parking occupancy detection for gas stations, employing Haar-AdaBoosting and convolutional neural networks. This approach achieved an accuracy rate of not less than 94% in monitoring fueling parking spaces.

In conclusion, recent research has shown promising results in addressing the challenge of parking occupancy prediction using computer vision with location awareness. The advancements in CV algorithms, lightweight neural networks, multi-camera systems, and computational photography have improved the accuracy and efficiency of parking surveillance systems. However, further research is necessary to better understand 3D space and enhance object tracking capabilities, enabling accurate prediction of parking positions and optimizing parking space utilization in smart cities (Stojanović, Damjanović, Vukmirović et al., 2021).

## 2.4 Smart Vehicle Parking System Using (CV) and (IoT)

The research on Smart Vehicle Parking Systems utilizing computer vision and IoT technologies has gained significant attention in recent years due to the growing need for efficient parking management in urban areas.

One approach proposed by Thomas and Kovoor (2017) introduced a self-determining streetcar framework and a genetic algorithm to automate vehicle parking at shopping centers. The genetic algorithm optimized parking space utilization and streetcar efficiency, reducing waiting times for customers. The proposed system demonstrated improved efficiency without compromising on reduced waiting times compared to a system without the genetic algorithm.

In the pursuit of creating a smarter city and addressing parking-related challenges, Amiri et al. (2019) presented an IoT-based prototype for parking monitoring and management. The model aimed to provide a problem-free parking experience for the public while also generating revenue for the local government. The system monitored parking spot availability through IoT technology and automated the ticketing process through mobile apps, enabling users to reserve parking spaces and make online payments conveniently.

The increasing number of vehicles in congested urban areas has led to issues such as traffic congestion, air pollution, and wasted time searching for parking spots (Giuffrè et al., 2012; Shoup, 2006; Li et al., 2016). To alleviate these problems, Smart Parking Systems are being designed to efficiently manage parking space allocation.

To ensure the privacy of drivers while using parking facilities, Amiri et al. (2019) proposed a privacy-preserving smart parking system based on blockchain and private information retrieval. A consortium blockchain ensured security and transparency among parking lot owners, while private data retrieval allowed drivers to access parking space information without compromising their location privacy.

Incorporating Narrowband Internet of Things (NB-IoT) technology, Shi et al. (2017) presented a smart parking system that efficiently managed parking facilities through cloud-based data management, payment processing, and sensor node observation. The integration of an external payment platform facilitated easy and convenient payment options for drivers, enhancing the usability of the mobile application.

Addressing parking supervision challenges, Sadhukhan (2017) introduced an IoT-based E-Parking System for Smart Cities. The system enabled drivers to access real-time parking space availability information and reserve parking slots through an intuitive graphical user interface. Additionally, the proposed framework facilitated automatic collection of parking fees through smart payment options.

The deployment of a smart car parking system in smart cities was proposed by Alsafery et al. (2018). The system aimed to minimize the time spent searching for available parking spaces by providing users with real-time traffic congestion status. Data filtering and fusion techniques were employed to reduce transmitted data while ensuring efficient data processing using cloud-based machine learning algorithms.

Furthermore, Mahmood et al. (2018) developed a fully automated vehicle parking system utilizing computer vision. The system employed cameras at the entrance and exit of parking areas, capturing and comparing driver face images for identity verification. Although the proposed article location module showed high accuracy, the face recognition algorithm's image resolution handling required further attention.

To leverage the capabilities of Google's IoT technology, Shinde et al. (2017) introduced an intelligent parking android gadget. The user-friendly interface of the android application provided accurate parking information, ensuring efficient parking space allocation and reducing accidents and pollution.

Concurrently, Vakula and Kolli (2017) addressed parking issues in Hyderabad city with a low-cost smart parking system. The online-based booking and management system allowed users to check the availability of parking spaces, make online payments, and receive a generated barcode for easy access. Ultrasonic sensors were integrated into each parking slot to determine its occupancy status.

In conclusion, recent research in the field of Smart Vehicle Parking Systems using computer vision and IoT technologies has shown promising results. These studies have presented efficient and innovative solutions to optimize parking space utilization, enhance user experience, and address challenges associated with parking management in urban areas. The integration of IoT, cloud-based data management, blockchain, and advanced algorithms promises to revolutionize parking systems and contribute significantly to the development of smart cities.

The escalating urbanization and increasing number of vehicles have given rise to a pressing problem of finding suitable parking spaces in congested urban areas. This issue leads to traffic congestion, heightened fuel consumption, and increased carbon emissions (Taylor, Ezekiel, & Emmah, 2021). In response to this challenge, researchers have explored smart parking systems that leverage computer vision and Internet of Things (IoT) technologies to efficiently manage parking spaces.

One of the proposed approaches involves the use of Convolutional Neural Network (CNN) algorithms for vehicle detection in parking areas (Taylor, Ezekiel, & Emmah, 2021). (Taylor, Ezekiel, & Emmah, 2021) proposed an intelligent smart parking system that incorporates a CNN algorithm with a Haar cascade classifier for multiple vehicle detection in images and videos. The system achieved an impressive accuracy of 99.80% in identifying vehicles in parking spaces.

Another method explores the use of pre-trained models like Mask R-CNN for object detection in videos and images (Taylor, Ezekiel, & Emmah, 2021). However, while Mask R-CNN is capable of accurately identifying various objects, it may have limitations in detecting all vehicles in high-quality videos (Taylor, Ezekiel, & Emmah, 2021).

Integrating IoT with smart parking systems allows real-time monitoring of parking spaces. IoT sensors installed in smart parking systems provide crucial information on parking spot availability, enabling users to find and reserve parking spaces through mobile applications (Taylor, Ezekiel, & Emmah, 2021). This helps alleviate the challenge of finding empty parking spots in densely populated urban areas.

Efforts have been made to address the increasing traffic congestion caused by vehicles searching for parking spaces. Giuffrè et al. (2012) proposed a novel architecture for parking management in smart cities using IoT devices. The intelligent parking system utilizes IoT sensors installed in each parking space to detect occupancy status and shares this information with a service provider. As a result, drivers can access real-time data about available parking spots and make online reservations, streamlining the parking process.

In addition to CNN and IoT-based approaches, some researchers have explored the use of genetic algorithms for autonomous smart vehicle parking systems (Thomas & Kovoor, 2017). This approach optimizes parking decisions for autonomous vehicles, further improving parking efficiency in smart cities.

Furthermore, privacy-preserving smart parking systems that utilize blockchain and private information retrieval have been investigated (Amiri et al., 2019). These systems protect users' privacy while providing parking spot availability information.

Researchers have also developed smart parking systems based on Narrowband Internet of Things (NB-IoT) and third-party payment platforms (Shi et al., 2017). This system enables users to find parking spaces through IoT connectivity and facilitates convenient payments via third-party platforms.

Moreover, Sadhukhan (2017) proposed an IoT-based E-Parking System for Smart Cities. The system utilizes IoT technology to monitor and manage parking spaces in real-time, providing users with timely information on available parking spots.

Another significant contribution in this area is a low-cost smart parking system for smart cities proposed by Vakula and Kolli (2017). The system aims to make parking more accessible and efficient in urban areas, particularly for low-income communities.

Additionally, Alsafery et al. (2018) presented a smart car parking system solution for the Internet of Things in smart cities. This system employs IoT technologies to optimize parking space utilization and improve traffic flow in urban areas.

To enhance user convenience, Shinde et al. (2017) developed an IoT-based parking system using Google services. The system enables users to access real-time parking information through IoT connectivity and Google applications.

Furthermore, researchers have explored the use of Network Virtualization Optimization in Software-Defined Vehicular Ad-hoc Networks (Li et al., 2016). This approach enhances the efficiency and reliability of smart vehicle parking systems through network virtualization.

In conclusion, the combination of computer vision, IoT technologies, and advanced algorithms has shown promise in addressing the parking challenges in smart cities. Smart parking systems equipped with CNN algorithms and IoT sensors enable real-time parking space monitoring and reservation. As smart cities continue to evolve, further research and technological innovations are crucial to optimize parking management, alleviate traffic congestion, and promote sustainable urban development.

## 2.5 Development of Smart Parking Management System

The escalating growth in the number of vehicles on the roads has resulted in a pressing need for efficient parking management systems. Traditional parking methods often lead to challenges in finding available parking spaces, causing congestion, increased fuel consumption, and environmental pollution. To tackle these issues, researchers have introduced the concept of Smart Parking Systems, which leverage cutting-edge technologies to optimize parking space utilization and enhance user experience.

Smart Parking Systems encompass a wide range of solutions, and one of the central components is the development of a mobile application. This application serves as a user-friendly interface, providing real-time information about available parking spaces, allowing users to pre-book slots, and guiding them to the nearest parking lots (Lomat Haider Chowdhury et al., 2019). With the help of these applications, users can efficiently locate parking spaces, reducing the time spent searching for parking and easing traffic congestion.

An essential feature of Smart Parking Systems is the use of Image Processing techniques to identify vehicle registration plates. These techniques, integrated with sensors and cameras, facilitate the automatic opening and closing of parking lot gates whenever a vehicle approaches the entrance (Martynova, Kuznetsov, Porvatov, & Tishin, 2023). This automation not only streamlines the entry and exit process but also enhances security by preventing unauthorized access.

To detect the availability of parking spaces, Smart Parking Systems incorporate various hardware components, such as Reflective Type Infrared Proximity Sensors. These sensors can accurately identify whether a parking spot is occupied or vacant, enabling real-time updates about parking space availability (Vakula et al., 2017). The integration of such sensors with the mobile application ensures that users are provided with up-to-date information, allowing them to make informed decisions about where to park.

Additionally, the utilization of the Internet of Things (IOT) technology plays a significant role in the functionality of Smart Parking Systems. IOT enables the seamless connectivity of hardware components, allowing data to be collected and transmitted in real-time (Dudhe et al., 2017). This connectivity not only facilitates efficient parking management but also enables remote monitoring and control of the parking infrastructure.

The data collected by Smart Parking Systems is stored in the cloud, providing a centralized platform for managing parking-related information. The cloud integration enables seamless billing processes and allows users to make payments through the mobile application (Nitn Pandit et al., 2019). Moreover, with the data stored in the cloud, Smart Parking Systems can analyze parking patterns, optimize parking space allocation, and generate insights for improving overall parking management (Melnyk et al., 2019).

The future of Smart Parking Systems is promising, with potential enhancements in Artificial Intelligence and Machine Learning. Integrating these technologies can further improve vehicle identification, leading to better security measures and fraud prevention (Khanna and Anand, 2016). Moreover, the accumulated data in the cloud can be leveraged to provide personalized parking recommendations to users, tailoring the parking experience to individual needs (Das et al., 2019).

In conclusion, Smart Parking Systems offer an innovative solution to the challenges posed by urban parking. By leveraging advanced technologies such as Image Processing, IOT, and mobile applications, these systems enhance parking space utilization, reduce traffic congestion, and improve the overall user experience. The continuous development and integration of new technologies hold the potential to make Smart Parking Systems an indispensable part of smart city initiatives and significantly transform urban transportation.

The continuous rise in the number of vehicles has led to a growing challenge in finding appropriate parking spaces for each vehicle. To address this issue, the development of a Smart Parking System with a mobile application has been proposed, allowing users to access comprehensive information about parking spaces and efficiently manage them in the parking lot. The system incorporates Image Processing techniques to identify vehicle registration plates and offers autonomous door opening and closing operations upon detecting a vehicle at the entrance of the parking lot. Moreover, the mobile application provides real-time updates on available parking spaces and includes safety features such as fire and gas leak alerts.

The core control unit of the system is the Raspberry Pi, which manages and processes all the operations. A Liquid Crystal Display (LCD) is installed at the entry point of the parking lot to display current parking space availability, while Infrared (IR) proximity sensors are utilized to detect the presence of vehicles at the entry gate. By capturing images of vehicle registration plates, characters can be identified, and the Raspberry Pi can send a signal to a servo motor to open the gate for a specified interval, allowing the user to park the vehicle in the available slot. When the user leaves the parking space, the system records the date and time information, which is then used for billing purposes (Sudhakar, Reddy, Mounika et al., 2021).

The increasing number of vehicles and the misuse of available parking space have resulted in numerous parking-related issues. To optimize the use of parking spaces, the implementation of a Smart Parking System has become essential. By partially automating the process of identifying available parking lots, the system significantly reduces the time it takes for users to find suitable parking spaces, subsequently curbing fuel consumption, pollution, and traffic problems. The Smart Parking System consists of onsite hardware equipped with an IoT module for detecting parking space availability, integrating safety and security alerts, and capturing real-time information in the cloud. The associated mobile application enables users to access detailed information about parking space availability, pre-book slots, navigate to parking lots, and receive generated bills upon space utilization.

The Smart Parking System harnesses the power of IoT, allowing remote monitoring and control of the hardware components by connecting to the internet. This networking of physical components, including various sensors, enables real-time data sharing between devices (Sudhakar, Reddy, Mounika et al., 2021).

A review of related literature suggests that researchers have made significant strides in the development of intelligent parking systems. Haider Chowdhury et al. introduced a cost-effective Smart Car Parking Management System that stored parking slot information in a local host and used cloud storage for multiple parking lots, coupled with an image processing technique for vehicle number plate recognition (Haider Chowdhury et al., 2019). Dudhe et al. presented an overview of IoT and its applications, highlighting the relevance of IoT in home automation. Additionally, various studies have explored IoT-based Smart Parking Systems (Dudhe et al., 2017). These include research by Khanna and Anand (2016), Sadhukhan (2017), Nitin Pandit et al. (2019), and Mohd Nazri et al. (2020), demonstrating the growing interest and potential in this area.

The continuous progress in Smart Parking Systems paves the way for efficient urban mobility and resource management, contributing to the development of smart cities and sustainable transportation solutions (Sudhakar, Reddy, Mounika et al., 2021; Lai et al., 2021; Melnyk et al., 2019; Das et al., 2019; Vakula and Kolli, 2017). With ongoing advancements and the integration of new technologies, Smart Parking Systems are poised to revolutionize urban transportation and offer tailored solutions for the parking challenges faced in modern cities.

## 2.6 Computer Vision on a Parking Management and Vehicle Inventory

Computer vision is a cutting-edge technology that has found diverse and impactful applications in numerous fields, with relevance in parking management and vehicle inventory systems. At its core, computer vision revolves around the extraction of meaningful information from digital images and videos, enabling machines to interpret and understand visual data much like humans do. This multidisciplinary field draws from computer science, artificial intelligence, and image processing to develop algorithms and models that can perceive, analyze, and make decisions based on visual inputs (Volna & Kotyrba, 2014).

The process of computer vision involves several interconnected components that work in tandem to achieve accurate and reliable results. Image acquisition and preprocessing lay the groundwork by capturing visual data through cameras or sensors and then enhancing the images to improve clarity and remove noise (Caicedo, Robuste, & Lopez-Pita, 2006). Subsequently, feature extraction techniques are employed to identify key patterns, edges, shapes, and objects within the images (O'Mahony et al., 2019). These features are then analyzed and matched with existing patterns or object templates stored in the model's database (Zhang, 2019). Through machine learning algorithms and deep neural networks, computer vision models can continually improve their performance and accuracy over time, making them increasingly proficient at recognizing and interpreting visual information.

One of the remarkable applications of computer vision is in the domain of parking management. By deploying cameras in parking lots and utilizing image processing algorithms, the system can detect vacant parking spaces in real-time (Bukowski et al., 2019). This information can be relayed to drivers through mobile applications or electronic signboards, significantly reducing the time spent searching for parking spots and enhancing overall traffic flow. The potential benefits of such systems are vast, including reduced traffic congestion, lower carbon emissions, and increased revenue for parking facility operators (Bukowski et al., 2019).

Furthermore, computer vision's integration with deep learning techniques has led to breakthroughs in various parking-related applications. For instance, researchers have leveraged Convolutional Neural Networks (CNNs) to achieve exceptional accuracy in detecting parking lot occupancy (O'Mahony et al., 2019). Additionally, object detection models based on CNNs can identify and classify different types of vehicles for efficient vehicle inventory management in large storage facilities or car dealerships (Zhang, 2019).

Computer vision has also been harnessed to enhance road safety, particularly in the context of self-driving or autonomous vehicles. Cameras and sensors equipped with computer vision capabilities can identify pedestrians, cyclists, and obstacles on the road, enabling autonomous vehicles to navigate safely in complex environments (Sztyber, 2019). The ability to analyze and interpret visual data in real-time is crucial for the decision-making processes of self-driving cars, ensuring they can respond appropriately to dynamic road conditions.

Moreover, computer vision has proven to be instrumental in aiding visually impaired individuals, significantly contributing to their mobility and independence. By employing advanced image recognition algorithms, wearable devices can assist visually impaired pedestrians in navigating urban environments, recognizing crosswalks, traffic signals, and other crucial visual cues (Li, Cui, & Rizzo, 2019). Such systems provide auditory cues or haptic feedback to convey information about the surroundings, allowing visually impaired individuals to travel more confidently and securely.

Beyond parking and transportation, computer vision has broader implications for urban planning and management. Aerial imaging and analysis have been utilized to survey and map urban areas, identifying patterns of traffic flow, congestion, and parking demand (Ho et al., 2019). These insights can inform city planners and policymakers to make data-driven decisions for optimizing transportation infrastructure and creating smarter, more efficient cities.

In conclusion, computer vision is a transformative technology with a myriad of applications, including but not limited to parking management and vehicle inventory systems. By combining image processing, deep learning, and artificial intelligence techniques, computer vision enables machines to perceive and understand the visual world. Whether it is facilitating parking spot detection, improving road safety, or aiding visually impaired individuals, the impact of computer vision on smart cities and transportation systems is profound. As research and development in this field continue to advance, we can expect even more innovative and life-changing applications of computer vision in the future.

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## Multi-Angle Parking Detection System using Mask R-CNN

In recent years, the field of parking space detection has witnessed significant advancements, aiming to address the growing challenges of urban parking management. Researchers have explored various approaches, including image-based and sensor-based systems, to accurately detect parking spot occupancy. Image-based systems leverage computer vision techniques to analyze images captured by cameras, allowing for real-time parking management. Past studies have employed methods such as Canny edge detection, support vector machines, and texture classifiers for this purpose (Lopez et al., 2019; Bong et al., 2008; Almeida et al., 2015). Additionally, deep learning-based techniques, especially convolutional neural networks (CNNs), have shown promising results in parking space detection (Nymbal and Klein, 2017).

Despite the efficiency of image-based systems, they often require labor-intensive manual labeling of parking spots, limiting their scalability for large parking lots. To overcome this limitation, researchers have integrated deep learning architectures like YOLO and Mask R-CNN into parking management systems (Jose et al., 2018; Amato et al., 2017; Cai et al., 2019). YOLO allows for real-time classification with multiple object tracking, while Mask R-CNN combines object detection and instance segmentation, enabling precise localization of parking spaces (He et al., 2017). These deep learning-based models offer both accuracy and scalability for parking space detection.

In contrast, sensor-based systems offer high accuracy but often require a complex infrastructure setup and are expensive to implement and maintain. For instance, some studies have utilized Bluetooth Low Energy (BLE) technology and magnetometers for parking lot management (Marso and Macko, 2019; Cheung et al., 2006). While these methods provide accurate results, they face challenges related to environmental conditions and the need for close proximity to vehicles.

To strike a balance between accuracy and cost-effectiveness, a novel Multi-Angle Parking Detection System using Mask R-CNN is proposed in this paper. The Mask R-CNN model, with its ability to handle multiple parking angles, promises to achieve accurate and efficient parking space detection without the need for extensive manual labeling. By combining the advantages of deep learning-based image analysis and the scalability of sensor-based systems, the proposed solution aims to optimize parking management and enhance urban mobility.

In summary, the field of parking space detection has witnessed significant progress, with image-based and sensor-based systems offering unique strengths and limitations. Deep learning techniques, such as YOLO and Mask R-CNN, have revolutionized parking space detection, providing both real-time capabilities and accurate results. By integrating these advancements, the proposed Multi-Angle Parking Detection System seeks to contribute to more efficient parking management solutions and improved urban mobility.

Parking space detection systems have gained significant importance due to the rapid urbanization and motorization in developing countries (Inrix, 2019). In response to the challenges posed by inefficient parking management, researchers have explored various methods for detecting occupied and vacant parking spaces. The literature review highlights two categories of parking space detection systems image or camera-based systems and sensor-based systems. In the image-based approach, computer vision techniques have been utilized, such as canny edge detection (Lopez et al., 2019) and convolutional neural networks (CNNs) (Nyambal & Klein, 2017), to classify parking spots as occupied or empty. Other studies have used support vector machines (Bong et al., 2008) and texture classifiers (Almeida et al., 2015) for creating parking management systems. However, these methods often require extensive manual labeling of parking spots. To address this, deep learning-based approaches, such as Mask R-CNN, have been adapted to achieve real-time parking management (Amato et al., 2017).

These models can be trained on datasets like "Cars Overhead With Context" (COWC) (Senko et al., 2014) and "Common Objects in Context" (COCO) (Lin et al., 2014) for overhead and low-angle views, respectively. In contrast, sensor-based systems use technologies like Bluetooth Low Energy (BLE) for communication (Marso & Macko, 2019) and magnetometers for parking lot management (Cheung et al., 2006). While sensor-based solutions offer high accuracy, they necessitate an intensive infrastructure setup and are costly to implement and maintain (Faheem et al., 2013).

To evaluate the proposed Multi-Angle Parking Detection System, comprehensive datasets were acquired and pre-processed. The COWC dataset provided overhead views of parking spaces, and COCO dataset offered low-angle car detection images with associated masks. The PKLot dataset (Almeida et al., 2015) and CCTV footage from BITS Pilani Dubai University were used for testing the system's efficiency. The Mask R-CNN model, combining Faster R-CNN for object detection and FCN for instance segmentation (He et al., 2017), was employed for multi-angle car parking detection. Transfer learning was used to fine-tune the pre-trained model on the COWC dataset for overhead view detection.

For labeling parking spots and detecting occupied or vacant spaces, an automated algorithm was developed based on the assumption that parking spots are locations of stationary cars (He et al., 2017). This algorithm efficiently labeled parking spots using the detected cars' bounding boxes. To distinguish between vacant and occupied parking spaces, the Intersection over Union (IoU) measure was used with threshold values specific to the top-angle (Lopez et al., 2019) and low-angle views (Nyambal & Klein, 2017). The proposed system achieved high accuracy for both views, with IoU threshold values of 0.20 and 0.34, respectively. The results demonstrated the robustness of the proposed Multi-Angle Parking Detection System, offering scalability and adaptability to different parking scenarios. Although further improvements could be made to optimize processing and response times, the system presents a promising solution for efficient parking management and urban mobility enhancement. By combining the advantages of image and sensor-based approaches, this system contributes to revolutionizing parking management practices and addressing the challenges posed by increasing automobile traffic.

# **4. Proposed Methodology**

## Preliminaries

This section introduces some fundamental concepts and key terminologies related to the research problem of parking lot occupancy detection. Understanding these concepts is essential for comprehending the subsequent methodology employed in the development of the Real-Time Car Parking Occupancy Prediction System.

1. **Parking Lot Annotation**

In parking lots, individual parking spaces are typically demarcated by four-sided shapes, such as rectangles or squares. These shapes, also known as "quadrangles," are defined by four specific coordinates (x, y positions) representing the corners of each parking space. The process of identifying and marking these coordinates for each parking space is referred to as "parking lot annotation."

1. **Parking Lot Patch**

To facilitate car detection in parking lots, the entire parking lot image is divided into smaller, manageable regions, each representing a single parking space. These smaller regions are known as "parking lot patches." Each patch is essentially a mini-picture enclosed within a rectangular area, making it easier to focus on individual parking spaces during occupancy detection.

The parking lot occupancy detection problem can be approached in two primary ways

* 1. **Patch-Based Classification**

In the patch-based classification approach, the research focuses on analyzing individual parking lot patches independently. The goal is to determine whether each patch is "empty" (indicating that no car is parked in that particular space) or "occupied" (indicating that a car is present in the parking space). The system will classify each patch based on its occupancy status, enabling real-time monitoring of individual parking spaces.

* 1. **Intersection-Based Classification**

In contrast, the intersection-based classification approach considers the entire parking lot image as a cohesive unit. The system identifies specific regions of interest (ROIs) or "bounding boxes" within the image, which potentially contain parked cars. The objective is to estimate the likelihood of a car being present in each of these identified areas. This approach allows the system to predict parking occupancy based on a broader view of the parking lot.

By understanding these fundamental concepts of parking lot annotation, parking lot patches, and the two different approaches to occupancy detection, we cs`an now proceed to outline the detailed methodology used to develop the advanced Real-Time Car Parking Occupancy Prediction System. This comprehensive system aims to revolutionize parking management by providing real-time occupancy information and optimizing parking space utilization in urban environments.

## Data Preprocessing

1. **Data Collection**
   1. In order to develop and evaluate the Real-Time Car Parking Occupancy Prediction System, a diverse and representative set of datasets is crucial. The data collection process involves obtaining various parking lot images from different sources, each exhibiting unique visual conditions and environmental scenarios. The following steps outline the data collection process.
   2. Several publicly available parking lot occupancy datasets are considered for this research, each having its strengths and limitations. The selection process involves identifying datasets that encompass a wide range of visual conditions, weather scenarios, and occlusions to ensure the system's robustness and generalization ability.
   3. The chosen datasets include
      1. **PKLot**

This dataset comprises 12,417 images captured in various weather conditions, including sunny, overcast, and rainy. Though widely used for benchmarking, it is limited by its minimal occlusions due to camera positioning far from parking lots.

* + 1. **ACMPS**

With images captured from four different viewpoints during the daytime, ACMPS includes approximately 13,126 images and offers a moderate number of occlusions. Its weather variations are similar to PKLot.

* + 1. **CNRPark**

This dataset provides a closer view of parked cars and includes additional labels for different weather conditions. It presents extra occlusions between cars and other objects, such as trees or lampposts.

* + 1. **ACPDS**

Although the smallest dataset, ACPDS compensates with a high number of unique viewpoints and visual categories. It introduces a challenge due to perspective distortions from a wide-angle camera setup.

* + 1. **SPKL**

To address the lack of wintertime images in existing datasets, the research team collected 440 images including varying snow conditions from calm to blizzard. This dataset fills a critical gap in representing winter weather conditions.

* 1. Extract the images and their corresponding labels from each dataset.

1. **Data Standardization**
   1. Convert the annotations of parking lots from different datasets into a unified format.
   2. Verify the data for consistency and accuracy, and clean the data if necessary.
   3. Split the datasets into training, validation, and testing sets to ensure proper evaluation of the model.
2. **Data Augmentation**
   1. Apply image augmentation techniques to increase the diversity of the training data.
   2. Techniques such as rotation, flipping, resizing, and brightness adjustments can be used to augment the images.
3. **Extended Label Coverage**
   1. To accommodate specific visual conditions (e.g., fog, night, glare) not adequately represented in the existing datasets, the research extends the labels associated with each dataset up to 11 categories. This ensures a more comprehensive evaluation of the system's performance under various challenging scenarios.

## Algorithm Selection

1. **Object Detection Algorithm**
   1. EfficientNet-B03 is chosen as the backbone network for the occupancy detection algorithm due to its relatively lightweight and efficient performance.
   2. The architecture strikes a balance between model size and accuracy, making it suitable for real-time prediction tasks.
2. **Model Customization**
   1. Implement the EfficientNet-B03 architecture with depth wise convolutions, swish activation, and squeeze & excitation subblocks.
   2. Fine-tune the architecture for parking occupancy detection using transfer learning on the collected datasets.

## Training and Model Development

1. **Data Loading**
   1. Load the preprocessed datasets and create data loaders for efficient training.
   2. Utilize techniques like batch loading and shuffling to ensure better convergence during training.
2. **Model Training**
   1. Train the EfficientNet-P model on the training set using a suitable loss function, such as binary cross-entropy, as the prediction is a binary classification task (occupied or vacant).
   2. Implement early stopping and model checkpoints to prevent overfitting and save the best-performing model during training.
3. **Hyperparameter Tuning**
   1. Conduct hyperparameter tuning to optimize model performance.
   2. Explore different learning rates, batch sizes, and regularization techniques through grid search or random search.

## Integration of Location Awareness

1. **3D Representation of Parking Environments**
   1. Integrate location data with the occupancy prediction system to create 3D representations of parking environments.
   2. Utilize available location information (e.g., GPS coordinates) to create a virtual representation of the parking lot.
2. **Location-Based Slot Allocation**
   1. Use the 3D representation to optimize parking slot allocation based on real-time occupancy predictions and available parking spaces.
   2. Implement algorithms like space-filling curves or grid-based methods to efficiently allocate parking slots.

## Development of Intelligent Parking Manager Agent

1. **Implementing the Intelligent Parking Manager Agent**
   1. Develop the Parking Manager Agent using Reinforcement Learning techniques.
   2. Utilize a suitable algorithm, such as Deep Q-Network (DQN), to enable the agent to learn and adapt in real-time to changing parking patterns.
2. **Dynamic Slot Reallocation**
   1. Enable the Parking Manager Agent to dynamically reallocate parking slots based on real-time occupancy predictions and user demand.
   2. The agent should optimize space utilization and reduce congestion within the parking environment.

## User-Friendly Mobile Application

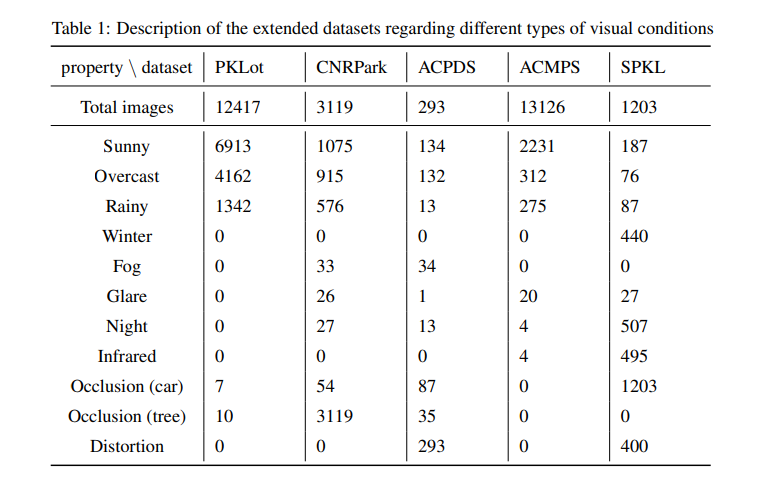
1. **Designing the Mobile Application**
   1. Design a user-friendly mobile application with an intuitive interface.
   2. Allow users to interact with the system, view real-time parking availability, and receive notifications about their allocated slots and penalties.
2. **Application Integration**
   1. Integrate the mobile application with the Real-Time Car Parking Occupancy Prediction System to provide real-time updates to users.

## Performance Evaluation

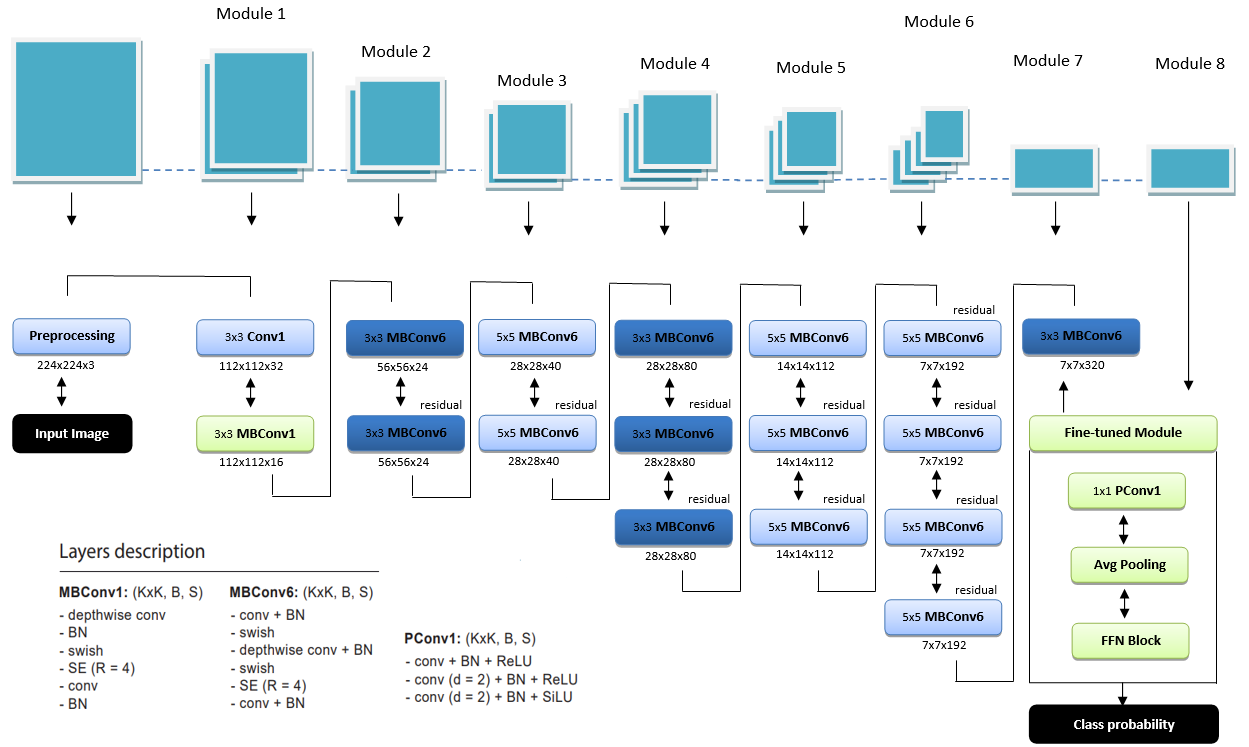
1. **Model Evaluation**
   1. Evaluate the trained model on the validation and test datasets using metrics such as accuracy, precision, recall, F1 score, and area under the receiver operating characteristic (ROC) curve.
   2. Assess the model's ability to predict parking occupancy in different weather conditions and lighting environments.
2. **System Evaluation**
   1. Evaluate the overall performance of the Real-Time Car Parking Occupancy Prediction System.
   2. Assess the system's efficiency in improving illumination factors, detecting incorrect parking placement, optimizing parking allocation, and enhancing cost efficiency.

## Result Analysis and Interpretation

1. **Analyze the Results**
   1. Perform a detailed analysis of the performance metrics obtained from both the model evaluation and system evaluation.
   2. Compare the results with the research objectives to determine the success of the proposed system.
2. **Interpretation**
   1. Interpret the results to draw meaningful conclusions and insights about the Real-Time Car Parking Occupancy Prediction System's efficacy.



## Architecture Diagram

Figure 1 EfficientNet-P model. The custom module follows first seven blocks of the original EfficientNet-B0.

The architecture of the EfficientNet-P model is depicted in Figure 1. The model comprises two main types of convolution blocks MBConv1 and MBConv6, arranged in sequential modules.

In the MBConv1 block, the input undergoes depthwise convolution, followed by swish activation and the Squeeze & Excitation (S&E) block. Depending on the specific module, the last convolution may be extended by a residual connection.

In contrast, the MBConv6 block starts with a regular convolution layer paired with batch normalization. After the swish activation, it applies depth wise convolution and the subsequent S&E block.

The last module in the pipeline is the original part fine-tuned from EfficientNet-P, which includes dilated convolutions with ReLU and SiLU activation functions applied subsequently.

Overall, the EfficientNet-P model is a carefully designed architecture that effectively combines different types of convolutional blocks and activation functions to achieve efficient and powerful object detection for the Real-Time Car Parking Occupancy Prediction System.

The proposed methodology aims to develop an advanced Real-Time Car Parking Occupancy Prediction System that enhances parking management efficiency and improves user experience in urban environments. By integrating location awareness and utilizing computer vision techniques, the system aims to revolutionize parking management and contribute to the field of intelligent parking systems.

## Research Methodology

1. **Introduction**

The research aims to develop an advanced parking management system using cutting-edge technologies, including object detection, real-time monitoring, and intelligent slot allocation. The system will enhance parking space utilization, automate management processes, and improve the overall user experience.

1. **Module-1 (Object Detection)**

In the initial phase of the research, the focus is on implementing an effective object detection system to identify vehicles, specifically cars, entering the parking area. This involves a series of steps:

* 1. **Image Capture**

Surveillance cameras are strategically placed at the parking entrance to capture images of incoming vehicles.

* 1. **License Plate Detection**

The captured images are subjected to object detection algorithms that identify whether the object is a car. If confirmed as a car, the system proceeds to extract the license plate number.

* 1. **Local Server Processing**

The image, along with the detected license plate, is transmitted to a local server for further processing.

* 1. **Edge Detection**

Image processing techniques are applied to localize the vehicle's edges within the image.

* 1. **Character Segmentation**

The license plate characters are segmented from the image, preparing them for recognition.

* 1. **License Plate Verification**

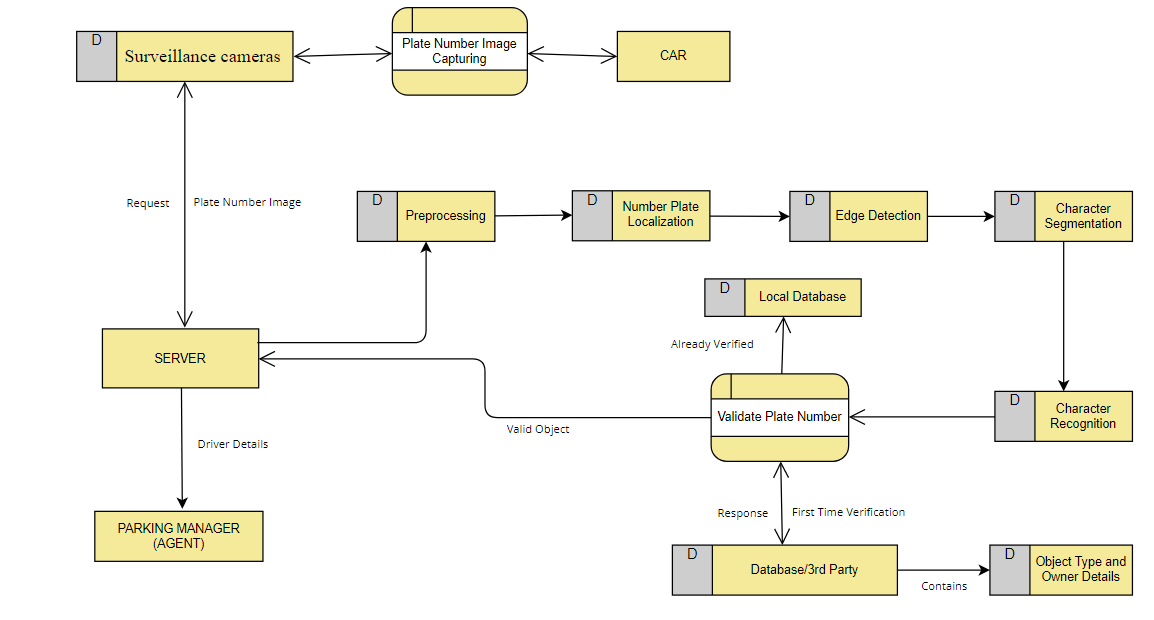
To verify the vehicle's authenticity, the segmented license plate is cross-referenced with a 3rd party database or API connected to government excise and taxation records. If the vehicle is validated, its ownership details are retrieved.

* 1. **Local Database**

For future reference, the system stores the data of verified vehicles, including license plate number, ownership details, and entry timestamps.

* 1. **Owner Details**

The collected data, comprising vehicle and owner information, serves as a basis for maintaining records and enforcing penalties for parking rule violations.



1. **Module-2 (Monitoring)**

The second phase revolves around the role of the Parking Manager, who oversees various aspects of the parking area and user interactions:

* 1. **Driver's Profile**

The Parking Manager extracts driver information, such as name, CNIC number, mobile number, and address, from the license plate data.

* 1. **Vehicle Details**

Alongside driver details, the system collects vehicle information like the license plate, car model, and engine number.

* 1. **Parking Fee Details**

The Parking Manager maintains a comprehensive record of parking fees, allowing for customization based on different factors. This includes hourly rates, penalties for exceeding time limits, and any additional charges.

* 1. **Parking Duration Details**

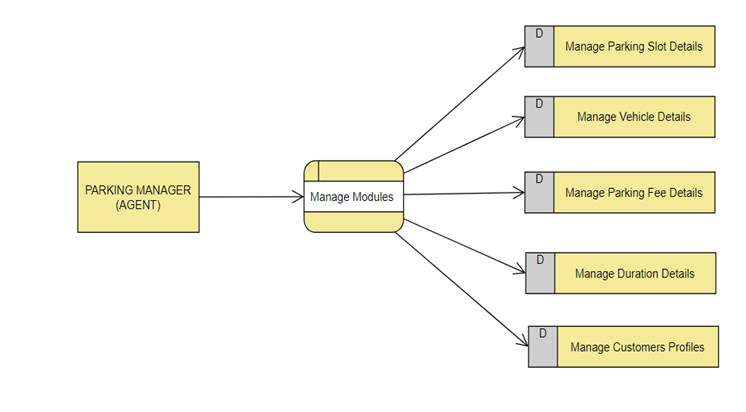
The system tracks the duration for which a car occupies a parking slot, calculating the time interval between entry and exit.

* 1. **Parking Slot Details**

Through continuous monitoring of surveillance camera images, the Parking Manager manages the occupancy status of parking slots. These images help to update the status of available and occupied slots.

* 1. **Notifications**

The Parking Manager is responsible for sending notifications to users when they violate parking rules, exceed time limits, or require payment for parking.



**4. Module-3 (Allocation of Parking Slot)**

The final phase focuses on streamlining the process of parking slot allocation and reallocation for optimum space utilization

* 1. **User Interface**

A mobile application offers users an interactive platform to request parking slots, view slot availability, and interact with the system.

* 1. **Slot Allocation**

Users can select available parking slots within a defined time frame through the mobile app. If users fail to do so, the Parking Manager takes charge and allocates the most suitable slot using image processing techniques on available slot images.

* 1. **Slot Reallocation**

In the event of a user vacating their slot, the Parking Manager reallocates it to other users, ensuring efficient utilization of parking space.

* 1. **Slots Unavailability**

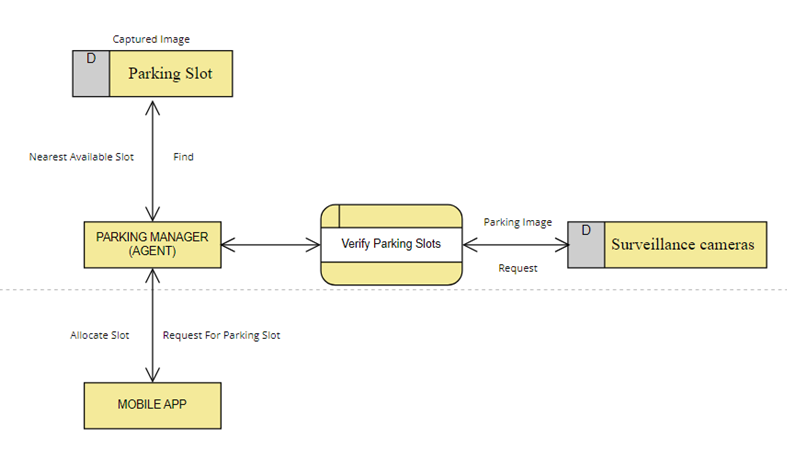
If no parking slots are available, the user is promptly notified to exit the parking area and make a new entry at a later time.

* 1. **Vacating Slots**

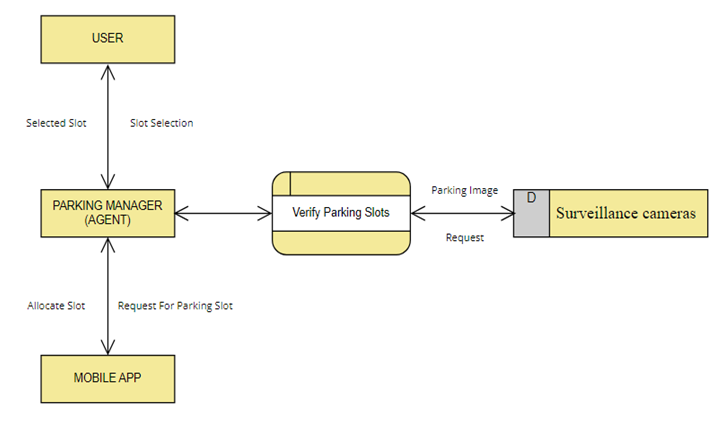
Users are required to indicate when they are leaving their allocated slot. This can be done manually through the app or automatically through a timeout mechanism.

* 1. **Reminder Notifications**

Automated reminders are dispatched to users who haven't released their parking slots after a specific duration. These reminders can be sent through the mobile app, SMS, or email.



**Allocation of Slot by Parking Manager**

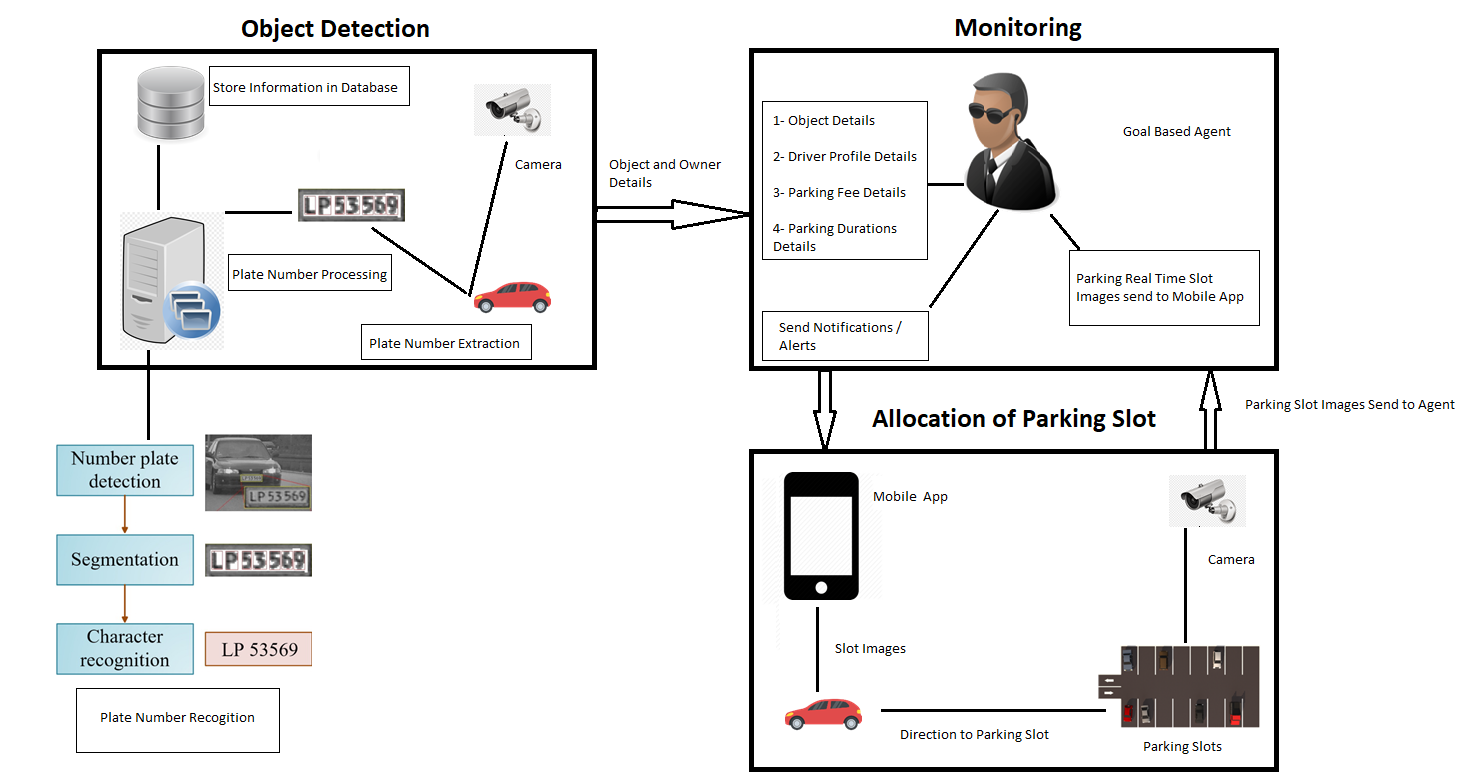
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**Allocation of Slot by User**

**5. Conclusion**

This research methodology outlines a systematic approach to developing an advanced parking management system. By incorporating object detection, real-time monitoring, and intelligent slot allocation, the system aims to optimize parking space, enhance user convenience, and automate various administrative tasks. The methodology ensures a holistic and comprehensive understanding of the research process.

## Proposed Model



# **Results and Discussion**

This section presents the findings obtained from the conducted computational experiments. We set up our experiments to assess both intersection-based and patch-based approaches using various backbone networks for object detection. Additionally, we evaluated the performance of vision transformers on parking lot occupancy detection tasks.

## Experimental Setup

The Experimental Setup section of the research paper outlines the key elements and procedures used in conducting the computational experiments to evaluate the performance of different parking lot occupancy detection models. It provides details on the datasets, models, training configurations, evaluation metrics, and data augmentation techniques used during the experiments.

1. **Datasets**

The research utilized several publicly available datasets to comprehensively evaluate the performance of the proposed parking lot occupancy detection models. The datasets included PKLot, ACMPS, CNRPark, ACPDS, and SPKL, each with its own unique characteristics. These datasets were carefully chosen to represent a wide range of visual conditions, weather conditions, occlusions, and perspectives typically encountered in real-world parking scenarios.

1. **Models**

The research evaluated different types of models, including intersection-based and patch-based approaches, to compare their performance. Intersection-based models involved using object detection architectures like Faster-RCNN and RetinaNet with different backbone networks such as ResNet50, MobileNet, and VGG-19. Patch-based models included conventional convolutional neural networks (CNNs) like VGG, AlexNet, and ResNet, along with domain-specific neural networks like CarNet and contrastive occupancy detection. Vision transformers, such as ViT, DeiT, and PiT, were also tested to explore their effectiveness in parking lot occupancy detection.

1. **Training Configuration**

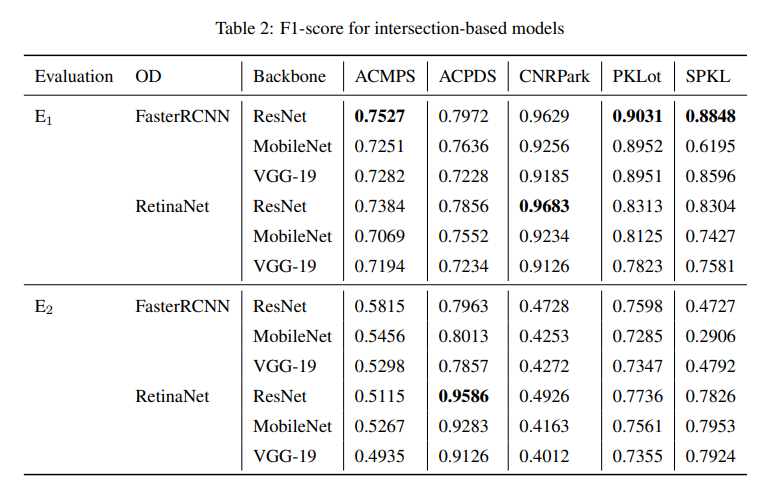
To train the models, the images from the datasets were preprocessed by resizing them to a standard size of 224x224 pixels. Data augmentation techniques, such as random rotation (±15 degrees) and horizontal flipping, were applied to increase the diversity of the training data and improve the models' generalization capabilities. Additionally, channel-wise normalization was performed to standardize the pixel values across the images. The models were trained on 10 Tesla V100 GPUs with the Adam optimizer using a learning rate suited for each architecture.

1. **Evaluation Metric**

The main evaluation metric used to measure the performance of the models was the F1-score. The F1-score is a commonly used metric for binary classification tasks like parking lot occupancy detection. It takes into account both precision (the proportion of true positives among the predicted positive labels) and recall (the proportion of positive labels that were correctly predicted). The F1-score provides a balanced measure of the model's accuracy and is particularly useful when there is a class imbalance in the dataset.

1. **Cross-Validation**

To ensure robust evaluation and mitigate biases, 5-fold cross-validation was employed. The dataset was split into five subsets, and each model was trained and evaluated five times, using a different subset as the validation set in each iteration. This allowed for a comprehensive assessment of the models' performance on different subsets of the data and helped to provide more reliable and generalizable results.



## Results of Intersection-Based Models

The section presents the findings and performance evaluation of different intersection-based models used for parking lot occupancy detection. Intersection-based models are based on object detection architectures, and in this research, two common architectures were used Faster-RCNN and RetinaNet. The section provides detailed information about the F1-scores obtained by these models on various datasets, including ACMPS, ACPDS, CNRPark, PKLot, and SPKL.

1. **Model Evaluation**

The research evaluated the performance of the intersection-based models using two different evaluation heuristics E1 and E2. E1 is based on the intersection-over-union (IoU) metric, which measures the overlap between predicted bounding boxes and ground truth annotations. E2, on the other hand, considers the distance between the centroids of parking lot annotations and car bounding boxes. Each heuristic has its strengths and weaknesses, and they were both used to comprehensively assess the models' performance.

1. **F1-Scores on Different Datasets**

The F1-scores obtained by the intersection-based models on various datasets are presented in tabular form. The datasets include ACMPS, ACPDS, CNRPark, PKLot, and SPKL, each representing different real-world scenarios and visual conditions. The F1-scores provide a measure of the models' accuracy in detecting occupied and vacant parking spots.

1. **Comparison of Backbone Networks**

The intersection-based models were evaluated with three different backbone networks ResNet50, MobileNet, and VGG-19. The F1-scores for each backbone network on different datasets were compared to identify which architecture performed best under various conditions.

1. **Performance Analysis**

The section discusses the overall performance of the intersection-based models on the different datasets. It highlights the strengths and weaknesses of each model, providing insights into their generalization capabilities and adaptability to varying visual conditions.

1. **Impact of Heuristic on Performance**

The research observes that the choice of evaluation heuristic (E1 or E2) has a significant impact on the model's performance. In most cases, the E1 heuristic performs better than E2, except for the ACPDS dataset. The differences in performance can be attributed to the way the two heuristics consider overlapping and shape information in the predicted bounding boxes.

1. **SPKL Dataset Challenge**

The SPKL dataset, which includes images with snow conditions, presents a challenge for the intersection-based models. The absence of snowfall images in other datasets makes it difficult for the models to generalize to this specific condition. As a result, the intersection-based models demonstrate lower F1-scores on the SPKL dataset compared to other datasets.

## Patch-Based Models Vision Transformers

The section focuses on the evaluation and performance analysis of patch-based models, particularly those based on vision transformers, for parking lot occupancy detection. Vision transformers are a recent advancement in computer vision, and they have shown promising results in various tasks, including image classification and object detection. This section explores how vision transformers perform when applied to the specific problem of parking lot occupancy detection.

1. **Patch-Based Approach**

The patch-based approach involves dividing an image into smaller patches and processing each patch independently. Vision transformers, in particular, have gained attention for their ability to capture long-range dependencies in images through self-attention mechanisms. This section investigates the effectiveness of vision transformers in handling parking lot images, where the presence of cars in different parking slots needs to be detected accurately.

1. **Experimental Setup**

The section provides details about the experimental setup used to evaluate the vision transformers. It includes information about the datasets used for training and testing, data augmentation techniques, and the configuration of the vision transformer models. The vision transformers considered for evaluation include ViT, DeiT, and PiT, each with its specific architecture and training strategy.

1. **SPT and LSA Techniques**

To enhance the performance of vision transformers on relatively small datasets, two techniques are applied Shifted Patch Tokenization (SPT) and Locality Self-Attention (LSA). SPT involves augmenting the training data with several translational augmentations, while LSA aims to improve attention distribution by suppressing diagonal components of the Key-Query matrix. These techniques are used to address the challenge of limited training data and improve the generalization of vision transformers on parking lot images.

1. **Performance Comparison**

The section presents a comparative analysis of the F1-scores obtained by different vision transformers on multiple datasets, including ACMPS, ACPDS, CNRPark, PKLot, and SPKL. The F1-scores provide a measure of the models' accuracy in detecting parking lot occupancy.

1. **Findings**

The experimental results reveal the performance of each vision transformer model on different datasets and visual conditions. The section highlights the strengths and weaknesses of each model, discussing which vision transformer architecture performs better under specific circumstances.

ViT vs. DeiT vs. PiT

The section compares the performance of ViT, DeiT, and PiT models. While ViT is the standard vision transformer, DeiT applies a teacher-student distillation strategy, and PiT introduces a token down sampling procedure. The comparison helps to understand how the architectural differences affect the models' performance in parking lot occupancy detection.

1. **Impact of Dataset Size**

The section discusses the impact of dataset size on the performance of vision transformers. Smaller datasets, such as ACPDS and SPKL, pose a challenge for vision transformers due to limited training samples. The findings shed light on the importance of data augmentation and model configuration in handling smaller datasets effectively.

## Patch-Based Models Convolutional Neural Networks

The section focuses on the evaluation and performance analysis of patch-based models using Convolutional Neural Networks (CNNs) for parking lot occupancy detection. CNNs are a widely used deep learning architecture known for their effectiveness in image-related tasks, including object detection.

1. **Patch-Based Approach**

The patch-based approach involves dividing an image into smaller patches and processing each patch independently. In the context of parking lot occupancy detection, this approach allows the model to focus on individual parking slots and make predictions based on local features present in each patch.

1. **Experimental Setup**

The section provides details about the experimental setup used to evaluate the patch-based CNN models. It includes information about the datasets used for training and testing, data augmentation techniques, and the configuration of the CNN models. Various CNN architectures, such as ResNet50, MobileNet, VGG-19, and others, are considered for evaluation.

1. **Performance Comparison**

The section presents a comparative analysis of the F1-scores obtained by different CNN models on multiple datasets, including ACMPS, ACPDS, CNRPark, PKLot, and SPKL. The F1-score is used as the evaluation metric to measure the accuracy of the models in detecting parking lot occupancy.

1. **Findings**

The experimental results reveal the performance of each CNN model on different datasets and visual conditions. The section highlights which CNN architecture performs better under specific circumstances and provides insights into the strengths and limitations of each model.

1. **Importance of Model Selection**

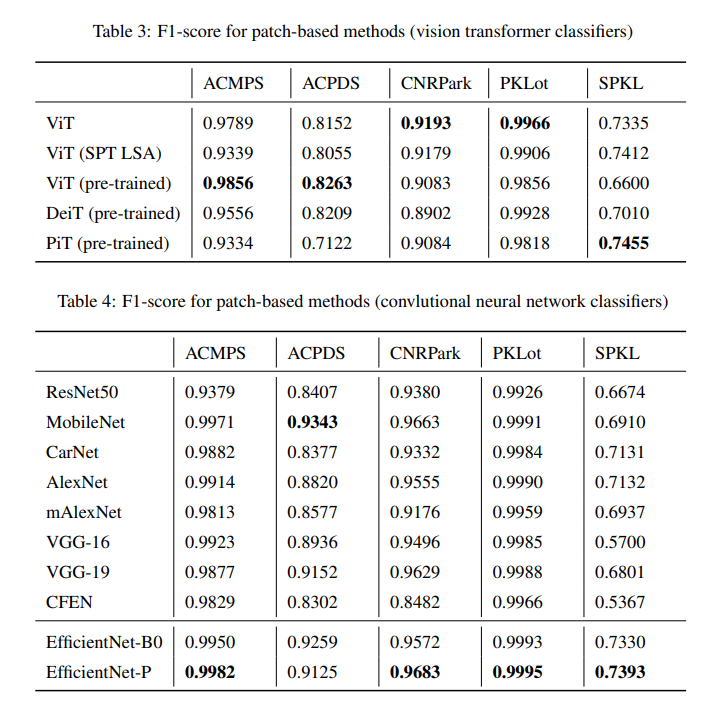
The section emphasizes the importance of selecting the appropriate CNN architecture for parking lot occupancy detection. Different CNN models have varying complexities and capabilities, which can significantly impact their performance on this specific task.

1. **Impact of Dataset Size**

The section discusses the impact of dataset size on the performance of CNN models. Smaller datasets, such as ACPDS and SPKL, may pose challenges for CNNs due to limited training samples. The findings shed light on the importance of data augmentation and model selection in handling smaller datasets effectively.

1. **EfficientNet-P Model**

The section also introduces the EfficientNet-P model, a customized version of the EfficientNet architecture tailored for parking lot occupancy detection. The EfficientNet-P model shows promising results and outperforms other CNN models in certain scenarios, as indicated by the F1-scores.



## Comparison of Patch-Based Models and Intersection-Based Approaches

The section aims to compare the performance of patch-based models using Convolutional Neural Networks (CNNs) and intersection-based approaches using Faster-RCNN and RetinaNet detectors for parking lot occupancy detection. The section analyzes the results obtained from computational experiments and discusses the strengths and weaknesses of each approach.

1. **Experimental Setup**

The section briefly reiterates the experimental setup used for both patch-based models and intersection-based approaches. It includes information about the datasets used, data augmentation techniques, evaluation metrics (F1-score), and the models' configurations.

1. **Intersection-Based Approach**

The section presents the results of the intersection-based approach using Faster-RCNN and RetinaNet detectors with different backbones, such as ResNet50, MobileNet, and VGG-19. The F1-scores for each model are reported on multiple datasets, including ACMPS, ACPDS, CNRPark, PKLot, and SPKL.

1. **Patch-Based Models**

The section focuses on the performance of patch-based models using various CNN architectures, such as ResNet50, MobileNet, CarNet, AlexNet, VGG-16, VGG-19, and others. The F1-scores for each model are reported on the same datasets as used in the intersection-based approach.

1. **Comparative Analysis**

The section provides a comprehensive comparative analysis of the F1-scores obtained from the intersection-based and patch-based approaches. It discusses the results for each dataset and highlights the models that perform better in different visual conditions.

1. **Performance on Different Datasets**

The section discusses how the performance of both approaches varies across different datasets. It identifies datasets where the intersection-based approach excels and datasets where the patch-based models show better predictive quality.

1. **Performance on Challenging Visual Conditions**

The section focuses on challenging visual conditions, such as fog, infrared images, glare, and night images. It highlights how each approach performs under these conditions and which models exhibit better generalization.

1. **Importance of Dataset Size**

The section considers the impact of dataset size on the performance of both approaches. It discusses how larger datasets contribute to better model performance and how smaller datasets may lead to challenges in training and evaluation.

1. **EfficientNet-P Model**

The section introduces the EfficientNet-P model as a customized version of the EfficientNet architecture for parking lot occupancy detection. It briefly discusses its performance and its potential to outperform other CNN models in certain scenarios.

## Patch-Based Models EfficientNet-P

The section delves into the performance of the EfficientNet-P model, which is a customized version of the EfficientNet architecture tailored for parking lot occupancy detection. The section presents the results of computational experiments conducted using EfficientNet-P and discusses its advantages over other patch-based models.

1. **Model Description**

The section begins by providing a detailed description of the EfficientNet-P model architecture. It explains how EfficientNet-P differs from the standard EfficientNet and highlights the modifications made to make it suitable for parking lot occupancy detection. Key components, such as grouped convolutions, residual connections, and exponential moving average, are explained in depth.

1. **Ablation Study**

An ablation study is conducted to investigate the impact of various modifications on the performance of EfficientNet-P. Different configurations of the final feed-forward network (FFN) block are tested to identify the most effective setup. The section presents the F1-scores for each variant and discusses their implications.

1. **Performance on Different Visual Categories**

EfficientNet-P's performance on different visual categories is analyzed. Visual categories represent specific visual conditions, such as fog, glare, infrared, night, and various weather conditions like sunny, overcast, rainy, and winter. The section provides a detailed comparison of F1-scores for EfficientNet-P, MobileNet, and contrastive occupation detection models for each visual category.

1. **Analysis of Improvements**

The section highlights the impact of different techniques applied to the EfficientNet-P model to improve its performance. Techniques such as grouped convolutions, residuers, exponential moving average, optimizer replacement, and batch accumulation are analyzed in terms of their effect on different visual categories.

1. **Comparative Performance**

EfficientNet-P's performance is compared with that of other patch-based models, such as ResNet50, MobileNet, CarNet, AlexNet, VGG-16, VGG-19, and others. The section discusses how EfficientNet-P outperforms or matches the performance of these models on different datasets and visual conditions.

1. **Advantages of EfficientNet-P**

The section provides a comprehensive overview of the advantages of using EfficientNet-P for parking lot occupancy detection. It discusses its ability to handle various visual conditions, its robustness to different datasets, and its potential for achieving state-of-the-art results.

1. **Applicability and Generalization**

EfficientNet-P's applicability and generalization capabilities are assessed across different datasets. The section discusses its potential for real-world deployment in parking management systems and its adaptability to diverse parking environments.

1. **Practical Considerations**

Practical considerations, such as model complexity, training time, and computational resources required for EfficientNet-P, are also addressed. The section discusses the trade-offs between performance and resource requirements and suggests potential ways to optimize the model for practical applications.

# **Limitations**

## Dataset Representativeness

The research relies on a selection of datasets, including PKLot, ACMPS, CNRPark, ACPDS, and SPKL, for evaluating the proposed parking occupancy detection system. However, these datasets may not fully represent the diversity and complexity of real-world parking scenarios. The performance of the proposed system may be influenced by dataset biases and may not generalize well to different geographic locations, parking lot layouts, and environmental conditions.

## Generalization to Open Parking Spaces

The research focuses on deterministic closed parking environments, such as malls, hospitals, and residential areas. As a consequence, the proposed system's applicability to open parking spaces, on-street parking, or unregulated parking areas remains uncertain. Open parking areas may present additional challenges, such as varying vehicle sizes, unrestricted parking patterns, and uncontrolled lighting conditions.

## Weather and Lighting Conditions

The datasets used for evaluation do not fully cover all weather and lighting conditions, such as heavy rain, extreme fog, or very low light conditions. The performance of the proposed system in adverse weather or lighting scenarios is not extensively evaluated, and its robustness in such conditions is unclear.

## Winter Weather Data

The lack of winter weather data in the existing datasets may limit the system's ability to accurately predict parking occupancy in snowy or icy conditions. Snowfall and reduced visibility during winter could significantly impact the performance of the proposed system.

## Real-Time Data

The research discusses the use of real-time data for parking occupancy detection, but it does not address the challenges associated with real-time data acquisition, processing, and integration into the system. Real-time data streams may introduce latency and require robust data handling mechanisms.

## Hardware and Computational Resources

The computational experiments were conducted on specific hardware configurations, including 10 Tesla V100 GPUs and 920 Gb of RAM. The research does not provide insights into the scalability and performance of the proposed system on different hardware setups or cloud-based platforms.

## Real-World Deployment

While the research proposes an advanced parking occupancy detection system, it lacks an in-depth analysis of the real-world deployment challenges. Factors such as installation and maintenance costs, integration with existing parking infrastructure, user privacy, and regulatory compliance are crucial for successful deployment but are not thoroughly addressed.

## Evaluation Metrics

The research primarily uses F1-score as the evaluation metric for model performance. While F1-score is informative, it may not capture all aspects of parking occupancy detection accuracy, such as false positives, false negatives, or precision-recall trade-offs.

## Comparison with State-of-the-Art

The research compares the proposed models with some existing approaches, but it may not comprehensively evaluate them against the latest state-of-the-art methods in the field of parking occupancy prediction and smart parking systems.

## Real-World Variability

The performance of the proposed system may vary in real-world scenarios due to factors beyond the scope of the datasets used for evaluation. Variability in vehicle types, parking behaviors, occlusions, and camera placements can affect the system's accuracy and reliability.

## User Interaction and Acceptance

The research discusses the design of a user-friendly mobile application but does not include a comprehensive user study or analysis of user acceptance and feedback. User perception, ease of use, and user behavior patterns are critical factors in the success of a practical parking occupancy prediction system.

## Ethics and Privacy

The research does not explicitly address potential ethical considerations and privacy implications related to parking lot surveillance, data collection, and user interactions. Ethical aspects, such as data privacy, consent, and potential biases in the system, need to be carefully addressed in the development and deployment of the proposed system.

In summary, while the research proposes a promising Real-Time Car Parking Occupancy Prediction System, it is essential to consider the comprehensive limitations mentioned above to ensure a realistic assessment of the system's capabilities, limitations, and practical applicability in real-world parking management scenarios.

# **Conclusion and Future Work**

## Conclusion

In this thesis, we have addressed the pressing concern of parking occupancy detection and prediction in urban areas through the development of a Real-Time Car Parking Occupancy Prediction System using Computer Vision with Location Awareness. The goal was to create an intelligent parking guidance system that enables drivers to search for available parking lots across various regions of interest in smart cities.

Throughout the research, we extensively evaluated and compared state-of-the-art parking lot occupancy detection algorithms, including patch-based and intersection-based approaches, with the emerging vision transformers. We also proposed a novel pipeline based on the EfficientNet architecture, referred to as EfficientNet-P, which demonstrated superior performance in parking lot occupancy detection when evaluated on five different datasets PKLot, ACMPS, CNRPark, ACPDS, and SPKL.

The results of the computational experiments revealed that the EfficientNet-P model outperforms existing solutions, including classic CNNs and other vision transformer models, in terms of predictive quality while maintaining manageable computational complexity. Its efficiency can be attributed to the combination of depth wise convolutions, swish activation, and squeeze & excitation subblocks, making it well-suited for real-time parking occupancy prediction tasks.

However, it is essential to acknowledge the limitations of this research. One significant limitation is the lack of full representativeness of real-world parking scenarios in the datasets used for evaluation. While efforts were made to extend the datasets to include various visual conditions, the absence of winter weather data and the limited evaluation of extreme weather and lighting conditions may impact the generalization ability of the proposed system to diverse geographic locations and seasonal variations.

Additionally, the proposed system's evaluation was primarily focused on deterministic closed parking environments, such as malls, hospitals, and residential areas. The effectiveness of the system in open parking spaces and city streets remains an open question that requires further investigation.

Moreover, real-time data acquisition and integration challenges were not extensively addressed in this research, and real-world deployment considerations, such as scalability, hardware requirements, and privacy concerns, warrant careful attention in practical implementations.

In conclusion, the developed Real-Time Car Parking Occupancy Prediction System based on EfficientNet-P presents a significant advancement in parking management for urban areas. By providing real-time parking occupancy information and optimizing parking slot allocation, the system can help reduce traffic congestion and improve overall parking space utilization.

To further enhance the system's capabilities and overcome the identified limitations, future research directions should include collecting more diverse and representative datasets encompassing various visual conditions and weather scenarios. Additionally, investigating the system's performance in open parking spaces and dynamically changing environments is crucial for real-world applicability. Moreover, efforts should be made to address the challenges of real-time data acquisition and integration to ensure the system's responsiveness and scalability.

Overall, the proposed system has the potential to contribute significantly to the development of smart cities and urban planning by providing an intelligent and efficient solution for parking management. By continuously refining the model and considering user feedback, we can pave the way for a more sustainable and user-friendly parking experience in urban environments.

## Future Work

Firstly, improving the system's performance requires an Enhanced Dataset Collection. This entails gathering diverse and extensive datasets that encompass various visual conditions, weather scenarios, and parking environments. By doing so, the model's generalization to different geographic locations and seasonal variations can be enhanced, making it more reliable in real-world situations.

Secondly, Real-Time Data Acquisition is crucial for the system's responsiveness. This involves developing efficient mechanisms to acquire and process data in real-time. Integrating real-time camera feeds, sensor data, and intelligent data fusion techniques can lead to more accurate parking occupancy predictions and enable a dynamic parking management system.

To ensure the system's practical implementation, Scalability and Deployment Considerations must be taken into account. This includes investigating the hardware requirements and optimization strategies necessary to handle large-scale data and real-time processing effectively. Scalability is essential for the system to be deployable in diverse urban areas and smart cities.

Expanding the research to include Open Parking Space Detection is another vital aspect. This means incorporating street parking and other open parking spaces into the system's predictions. These areas pose unique challenges due to different traffic patterns and less controlled environments, requiring the development of specialized algorithms for accurate predictions.

Dynamic Parking Slot Allocation is another future direction. Optimizing the allocation and reallocation of parking slots based on changing demand patterns and traffic conditions can lead to more efficient space utilization and reduced congestion. Implementing intelligent Parking Manager Agents to adaptively manage parking spaces based on real-time data will be a key focus here.

Enhancing User Interaction and Mobile Application can greatly improve the system's usability. Developing a user-friendly mobile application that allows drivers to interact with the system, view real-time parking availability, and receive notifications about allocated slots and penalties will enhance the overall user experience. Incorporating user feedback and preferences can further personalize parking suggestions for individual drivers.

Integrating the parking occupancy prediction system with existing Smart City Infrastructure is another promising avenue. Collaboration with traffic management systems, navigation apps, and public transportation services can lead to more comprehensive urban planning and traffic management solutions.

Lastly, addressing Privacy and Security Considerations is of utmost importance. As the system relies on camera and sensor data, it is essential to implement privacy-preserving techniques and comply with data protection regulations to safeguard user privacy and ensure public acceptance of the technology.

By pursuing these future research directions, the Real-Time Car Parking Occupancy Prediction System can evolve into a valuable tool for smart city development, contributing to more efficient and sustainable urban transportation systems. Its integration with energy-efficient infrastructure, stormwater management, and waste management will further minimize environmental impacts in closed deterministic environments, fostering a greener and eco-friendly approach to parking management in urban areas.

In the context of future work for the thesis, several key aspects can be focused on to enhance the Real-Time Car Parking Occupancy Prediction System and broaden its applicability. Firstly, improving the system's performance can be achieved by collecting more diverse and extensive datasets, encompassing various visual conditions, weather scenarios, and parking environments. This will enhance the model's ability to generalize across different geographic locations and adapt to seasonal variations, ensuring its robustness and reliability in real-world applications.

Real-time data acquisition is vital to ensure the system's responsiveness, and thus, efforts should be made to develop efficient and reliable mechanisms for gathering real-time data. Integration of real-time camera feeds, sensor data, and intelligent data fusion techniques can bolster the accuracy of parking occupancy predictions, facilitating a more dynamic and effective parking management system.

The scalability and ease of deployment of the parking occupancy prediction system in diverse urban areas should also be considered in future research. Investigating hardware requirements and optimization strategies to handle large-scale data and real-time processing will be instrumental in enabling practical implementation in smart cities.

Furthermore, extending the research to include open parking spaces, like street parking, is valuable. These areas pose unique challenges due to different traffic patterns and less controlled environments. Therefore, developing algorithms to accurately predict parking availability in such spaces will greatly contribute to overall traffic management and utilization of parking resources.

To further optimize parking space utilization and alleviate traffic congestion, future research can delve into dynamic parking slot allocation. Implementing intelligent Parking Manager Agents that adaptively manage parking spaces based on real-time data can lead to more efficient space utilization and reduced congestion.

A user-friendly mobile application can enhance user experience by allowing drivers to interact with the system, view real-time parking availability, and receive notifications about allocated slots and penalties. Incorporating user feedback and preferences into the system can tailor parking suggestions to individual drivers, further improving user satisfaction.

The integration of the parking occupancy prediction system with existing smart city infrastructure is another area of potential future work. By collaborating with traffic management systems, navigation apps, and public transportation services, the parking system can contribute to more comprehensive urban planning and traffic management, fostering efficient urban mobility.

Addressing privacy and security concerns is paramount, given that the system relies on camera and sensor data. Future research should focus on implementing privacy-preserving techniques and ensuring compliance with data protection regulations to safeguard user privacy.

Finally, minimizing the potential environmental impacts of the closed deterministic system can be achieved through various means. Implementing energy-efficient infrastructure, promoting efficient space utilization, incorporating stormwater management techniques, and adopting waste management practices will collectively contribute to a more sustainable and eco-friendly parking system.

By incorporating these multifaceted future research directions, the Real-Time Car Parking Occupancy Prediction System can be further enhanced and emerge as a valuable tool for the development of smart cities. The system's contributions to more efficient and sustainable urban transportation systems will undoubtedly make a positive impact on future urban environments.

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