

**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.

## Major Contributions and Challenges

**1.1.1** **Object and** **Parking Occupancy Detection**

(Stojanović, Damjanović, Vukmirović et al., 2021) expresses various methods to address parking space scarcity, including hardware sensors for individual parking spaces and Computer Vision (CV) technology. In this study, the researchers propose an innovative architectural framework that takes advantage of the latest Smart Edge devices equipped with AI accelerators. This integration harnesses the recent advancements in computer vision (CV) algorithms, which have significantly improved precision and efficiency. The primary focus of our proposed approach is the utilization of Edge AI devices to autonomously compute parking occupancy.

By employing Edge AI Camera devices, we unlock capabilities that were once restricted to expensive server-side components. These devices now seamlessly incorporate AI and GPU modules capable of performing trillions of operations per second (TOPS). Furthermore, they offer support for high-resolution image sensors and utilize AI-driven auto-exposure, providing an advanced framework for image capture.

Another groundbreaking aspect of this research is the introduction of the concept of constructing three-dimensional (3D) models of parking environments using data streams from Edge AI cameras. This innovation enables the precise identification of available on-street parking spaces. By creating 3D bounding boxes around detected vehicles, as depicted in Figure 8, we significantly enhance tracking accuracy and effectively address complex parking challenges, including occlusions.

The research emphasizes the paramount importance of achieving comprehensive three-dimensional awareness for a deeper understanding of parking spaces and to leverage data fusion from GPS and camera attributes, enabling the calibration of camera orientation and perspective correction. The ultimate goal is to establish a robust platform for 3D environment modeling that greatly enhances prediction accuracy.

**1.1.1.1 Gaps, Issues and Problems**

In the context of this research conducted by (Stojanović, Damjanović, Vukmirović et al., 2021), several limitations and challenges have been identified. Firstly, the object detection process encountered a substantial volume of direct server requests with each detection attempt, leading to notable time delays and a reduction in overall efficiency. Secondly, the variability in lighting conditions, particularly in open street parking scenarios, posed significant challenges for accurate object and license plate number detection. Thirdly, the cost-effectiveness of previous studies was compromised due to the high expenses associated with the required hardware implementations. Lastly, a major limitation reported in prior research revolved around the accurate detection of parking placements and the complexities involved in reallocating parking spaces. These limitations and challenges, illustrated in Figure 1, underscore the need for innovative solutions in the research to address these issues effectively.

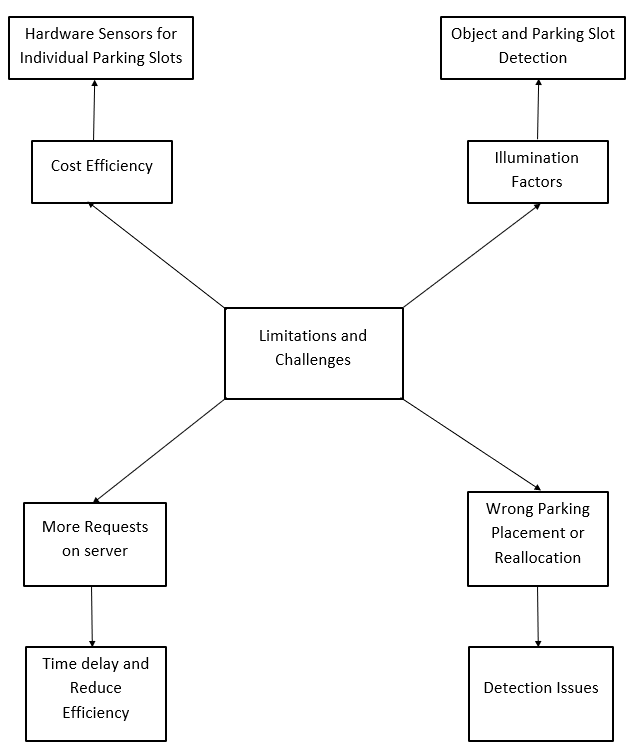


Figure 1. Limitations and Challenges in Parking Occupancy and Object Detection

**1.1.2 Optimize Techniques for Parking Slot Allocation**

The research conducted by (Taylor, Ezekiel, and Emmah in 2021) centers around addressing the critical urban problem of parking space scarcity and the resultant traffic congestion. Their approach leverages cutting-edge methodologies in object detection and predictive modeling to forge innovative solutions for optimize parking management.

A groundbreaking aspect of this research is the pioneering use of state-of-the-art object detection algorithms within the realm of parking management. By harnessing the capabilities of computer vision, these algorithms enable the automatic identification and tracking of vehicles within parking areas, offering a new dimension of efficiency and accuracy.

Through rigorous data collection and analysis, the researchers develop predictive models capable of foreseeing parking space availability. These models amalgamate historical and real-time data, providing valuable insights to drivers and empowering them to make informed parking choices.

Furthermore, the integration of Internet of Things (IoT) devices and edge computing plays a pivotal role in enabling real-time monitoring of parking occupancy. With the deployment of IoT sensors and edge devices, a network is established that continuously tracks and updates parking availability information, significantly benefiting urban mobility by reducing the traffic congestion stemming from drivers' quests for parking spaces.

By delivering precise and real-time information on parking availability, the researcher's work not only alleviates traffic congestion but also contributes to reducing carbon emissions associated with unnecessary vehicle circulation while searching for parking. This environmentally conscious approach aligns with sustainable urban practices.

Moreover, drivers themselves stand to gain from data-backed guidance, ultimately leading to improved parking experiences and a reduction in frustration.

This research not only addresses immediate challenges but also lays the groundwork for future advancements. The findings hold great potential for integration into broader smart city initiatives, enhancing overall urban efficiency. Additionally, the research extends its relevance to intelligent traffic management systems, with the potential to optimize vehicle flow within urban areas. In essence, this research makes a significant contribution to the ongoing transformation of urban environments towards smarter and more sustainable futures.

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. 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.

**1.1.2.1 Gaps, Issues and Problems**

The research conducted by (Taylor, Ezekiel, and Emmah in 2021) stems from a noticeable gap within the current body of literature. This gap is characterized by the absence of a holistic solution that adeptly combines cutting-edge image processing techniques, the capabilities of Internet of Things (IoT) technology, and the versatility of cloud-based solutions. This amalgamation is critically needed to orchestrate the optimization of parking slot allocation and management within closed deterministic environments effectively. The significance of this integration lies in its potential to craft a parking management system that seamlessly fuses these technologies, thereby tackling the persistent challenges associated with parking space availability head-on. By doing so, this research aims to not only elevate the user experience but also to lay the foundation for efficient and user-centric parking management practices, exemplified in Figure 2.

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.

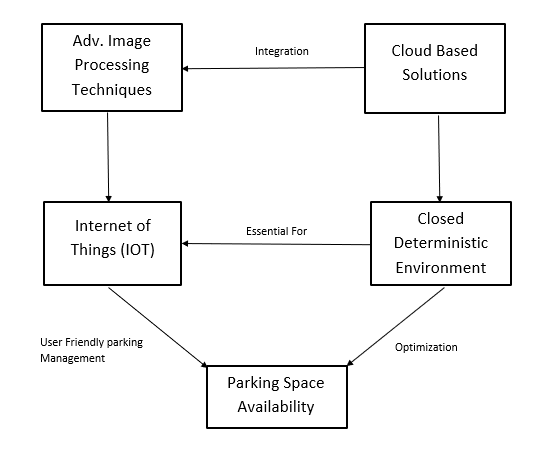


Figure 2. Advance Techniques to optimize parking slot Allocation

**1.1.3 Optimal Detection in Visual Conditions**

(Martynova, Kuznetsov, Porvatov, & Tishin, 2023) 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.

**1.1.3.1 Gaps, Issues and Problems**

The research by (Martynova, Kuznetsov, Porvatov, & Tishin, 2023) has indeed made substantial contributions to the field of parking lot occupancy detection. However, it also encountered several limitations and challenges throughout the research process.

One of the primary challenges addressed by the research was the inadequacy of existing architectures and methods used in parking lot occupancy detection. Despite extensive evaluations, it is important to acknowledge that there might still be limitations in the selected algorithms or techniques that were not fully uncovered.

Creating the Seasonal Parking Lot (SPKL) dataset was a commendable effort, but it's essential to recognize that even with this novel dataset, there may still be limitations in terms of real-world diversity and scale. The dataset creation process itself could have introduced biases or limitations, which should be acknowledged.

While enhancing the usability of existing datasets is valuable, it's worth noting that these augmented datasets may still have their own limitations. Augmenting datasets with additional labels and standardizing their storage format can improve comparability, but it may not entirely eliminate biases or limitations inherent in the original datasets.

The proposal of a novel approach using the EfficientNet architecture is a significant achievement. However, it's crucial to recognize that no single approach is universally optimal. There might be limitations or specific scenarios where the proposed method may not perform as well as other methods.

The computational experiments conducted by the researchers covered a wide range of approaches, architectures, and datasets, but the research should acknowledge that there might be other unexplored methodologies or datasets that could impact the results and conclusions.

Furthermore, while various optimization techniques were explored and applied, it's essential to recognize that the effectiveness of these techniques may vary across different datasets and scenarios. Some optimization techniques might have limitations or trade-offs that need to be considered.

While the research has made significant strides in addressing challenges and limitations in parking lot occupancy detection, it's important to maintain a degree of humility and acknowledge that there may still be unknown limitations and unexplored areas in this complex field.

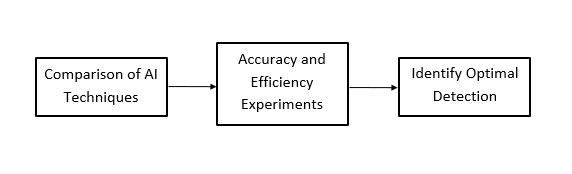


Figure 3. Optimal Detection in Visual Conditions

**1.1.4 Real-Time Automated Vehicle Parking Occupancy Detection and Navigation**

(Padmasiri, Madurawe, Abeysinghe et al., 2020) made several notable contributions to the field of automated vehicle parking occupancy detection. Firstly, their work presented the development of an end-to-end automated vehicle parking occupancy detection system designed to operate in real-time using surveillance streams. This system aims to efficiently guide drivers to available parking spaces, reducing time and energy expenditure. Secondly, the study introduced the application of advanced object detection techniques, specifically RetinaNet and Faster R-CNN, to accurately identify parking spaces under varying conditions. These techniques enhance the system's ability to detect both occupied and unoccupied parking spaces. Additionally, the proposed system adopted a modular software architecture with microservices, offering scalability and resilience while minimizing installation and maintenance costs. Lastly, the development of web and mobile applications as client interfaces enables users to locate parking spaces effortlessly. Most importantly, the approach eliminated the need for manual segmentation of video streams, making it adaptable and cost-effective for deployment across different parking lots.

**1.1.4.1 Gap, Issues, and Problems**

Several challenges and areas for improvement are evident in this study. Firstly, the limitations of the dataset used are acknowledged, and the system's performance could benefit from a fully annotated dataset. Future work should consider training on one parking lot and testing on another to provide more representative results. Secondly, the system has not been tested during night-ime due to the absence of a supportive dataset. Further research is needed to adapt the system for nighttime operation, expanding its applicability. Additionally, while the system excels at detecting occupied parking spaces, there is room for improvement in accurately detecting unoccupied spaces, especially in scenarios involving stray vehicles. To enhance real-world accuracy, the system could be improved by allowing users to manually enter the total number of parking spaces, enabling it to calculate unoccupied spaces based on detected occupied spaces. The study also discusses a comparison with existing approaches, highlighting its advantages, but it should consider further benchmarking against other systems. Lastly, the adaptability of the system to different parking space configurations and camera angles may require additional research and development to ensure its effectiveness across a wide range of scenarios.

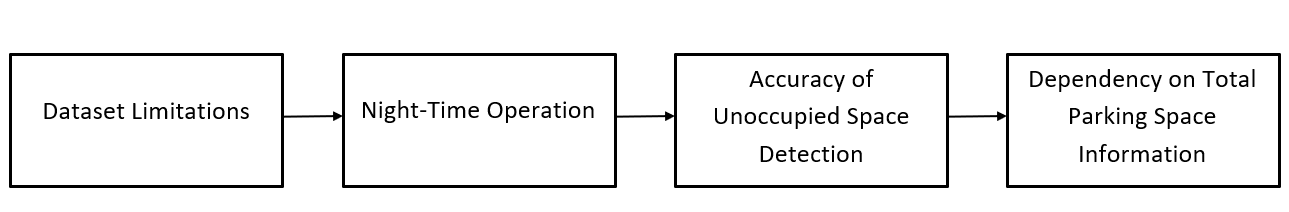


Figure 4. Innovative Approaches to Real-Time Automated Vehicle Parking Occupancy Detection and Navigation

**1.1.5 Multi-Clue Recovery Model for Accurate Parking Spot Detection**

This research makes several significant contributions to the field of automated parking spot detection (Chen, Qiu, Sheng et al., 2021). First and foremost, it introduces a novel Generative Parking Spot Detection (GPSD) algorithm that utilizes a multi-clue recovery model to effectively reconstruct parking spots. Unlike conventional methods, GPSD emphasizes the use of corners as fundamental components of parking spots, resulting in highly accurate detection and recovery.

Furthermore, the paper addresses the challenge of unbalanced illumination, partial information loss, and varying definitions of parking spot lines in input images by proposing a Layered Analytical Illumination Balance (LAIB) method for image preprocessing. This approach significantly improves the robustness of the algorithm under diverse lighting conditions.

The research also presents a Fast Micro-Target Detection (FMTD) algorithm, which prioritizes corner detection over traditional object classification methods. By doing so, it simplifies the training process while enhancing overall detection accuracy, particularly in scenarios involving complex parking spot shapes.

To correct and accurately locate parking spots, the paper introduces a multi-clue recovery model that leverages sideline, occlusion, edge, and domain clues. This comprehensive approach effectively addresses the issue of parking spot deformation, further improving the algorithm's performance.

Extensive experimental validation is conducted using datasets, including HERV 2018 and HERV 2019, demonstrating the superiority of the proposed algorithms. These experiments showcase exceptional results in corner detection, parking spot location, and overall detection quality, underscoring the contributions of this research.

**1.1.5.1 Gap, Issues, and Problems**

While the proposed GPSD algorithm excels in many aspects, it remains sensitive to parking spot deformation (Chen, Qiu, Sheng et al., 2021). Irregularly shaped or distorted parking spots pose a challenge that requires further investigation and refinement of the algorithm.

Another limitation is the relatively small size of the datasets used for validation, such as HERV 2018 and HERV 2019. These datasets may not encompass the full spectrum of parking scenarios, indicating the need for expanding the dataset to include a wider variety of scenes and environmental conditions. This expansion could provide a more comprehensive evaluation of the algorithm's performance.

The paper introduces an illumination balance method to address varying lighting conditions. However, it may still encounter difficulties in extreme or rapidly changing illumination environments, suggesting the necessity for additional improvements and robustness enhancements.

The research focuses on algorithm development and validation but does not delve into real-time implementation aspects. Deploying these algorithms in real-world scenarios, particularly in applications like autonomous vehicles, could introduce additional challenges related to computational efficiency and latency, which require further exploration.

Lastly, the generalization of the proposed GPSD algorithm to detect parking spots beyond common parallelogram layouts or in non-standard configurations remains an open question and an avenue for future research.

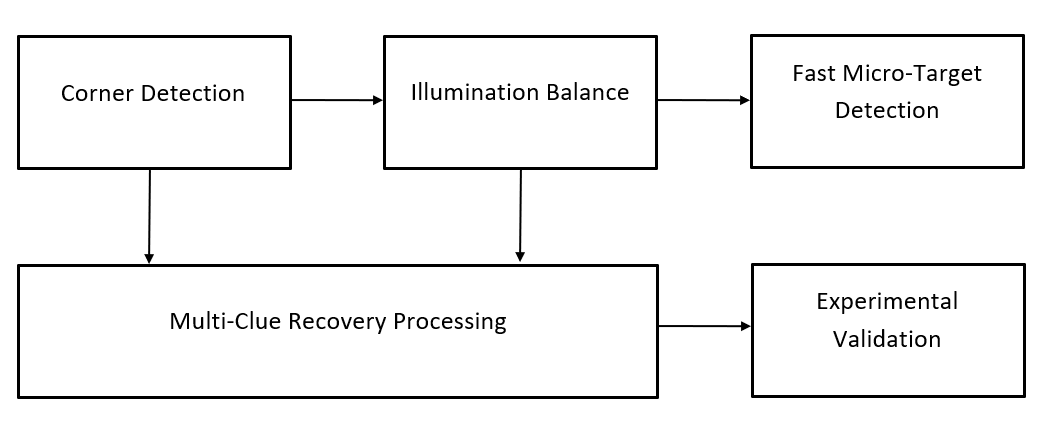


Figure 5. Multi-Clue Recovery Model for Accurate Parking Spot Detection Addressing Illumination and Deformation Challenges

## 1.2 Background of Study

**1.2.1 Challenges and Limitations in Parking Lot Occupancy Detection**

(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.

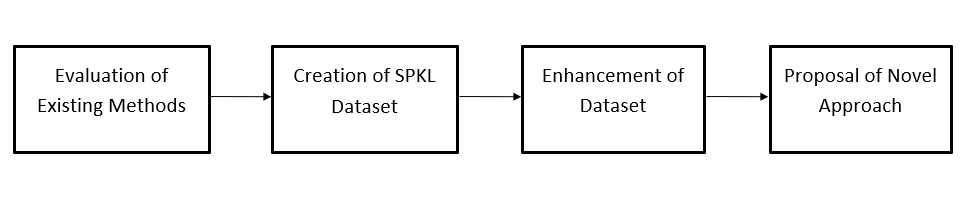


Figure 6. Martynova Challenges and Limitations in parking lot occupancy detection

**1.2.2 Exploration of Object Detection in Parking Lots**

(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.

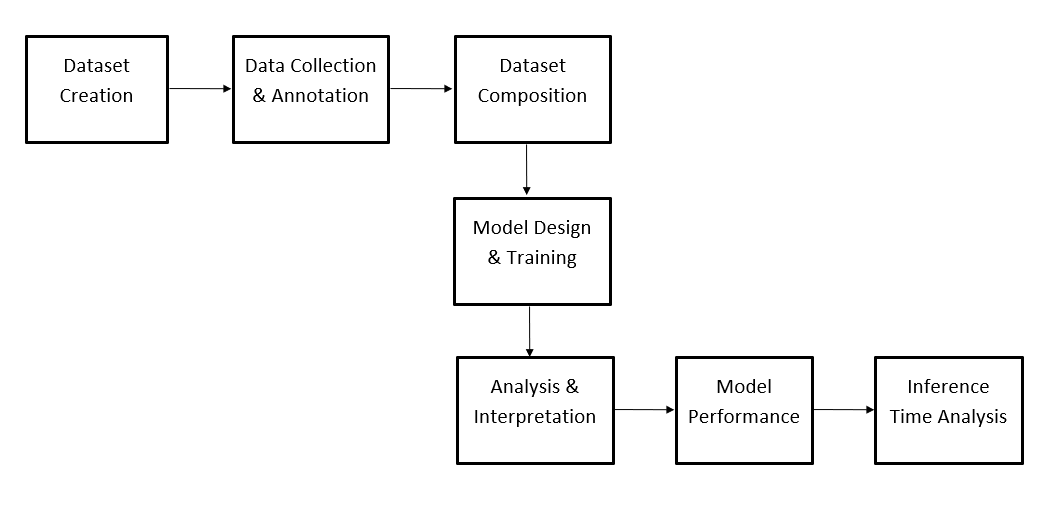


Figure 7. Marek comprehensive exploration of object detection in parking lots

**1.2.3 Challenges and Limitations for Efficient Parking Space Management**

(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.

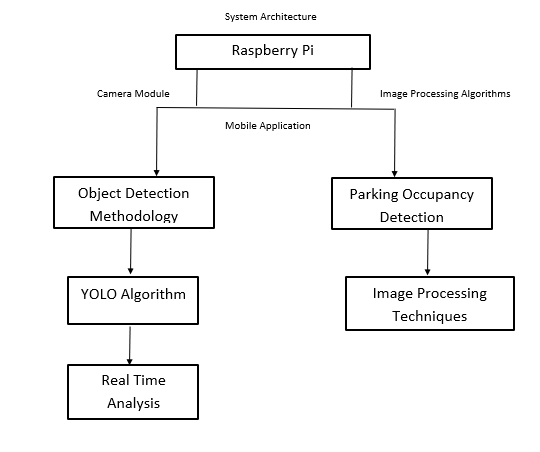


Figure 8. Sudhakar highlights Challenges and Limitations for efficient parking space management

**1.2.4 Critical Challenges of Parking Occupancy Detection in Urban Environments**

(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.

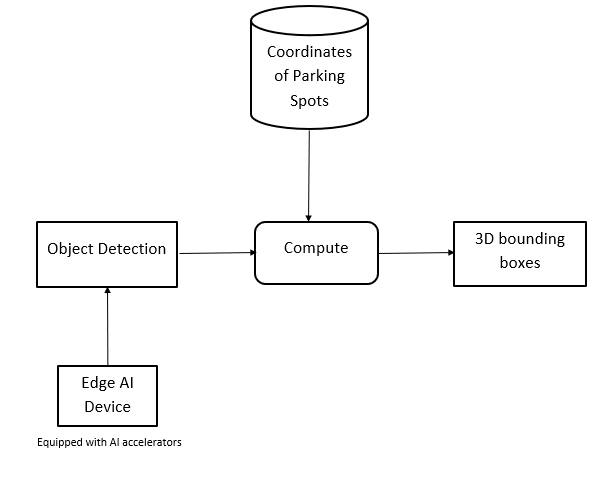
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Figure 9. Stojanović discussed Critical Challenges of Parking Occupancy Detection in Urban Environments

**1.2.5 Urban Issues of Parking Space Scarcity and its Consequential Traffic Congestion**

(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.

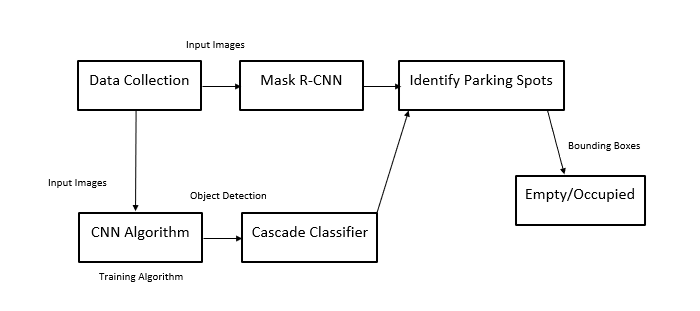


Figure 10. Taylor exposed Urban Issues of Parking Space Scarcity and its Consequential Traffic Congestion

## 1.3 Research Gap

**1.3.1 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.

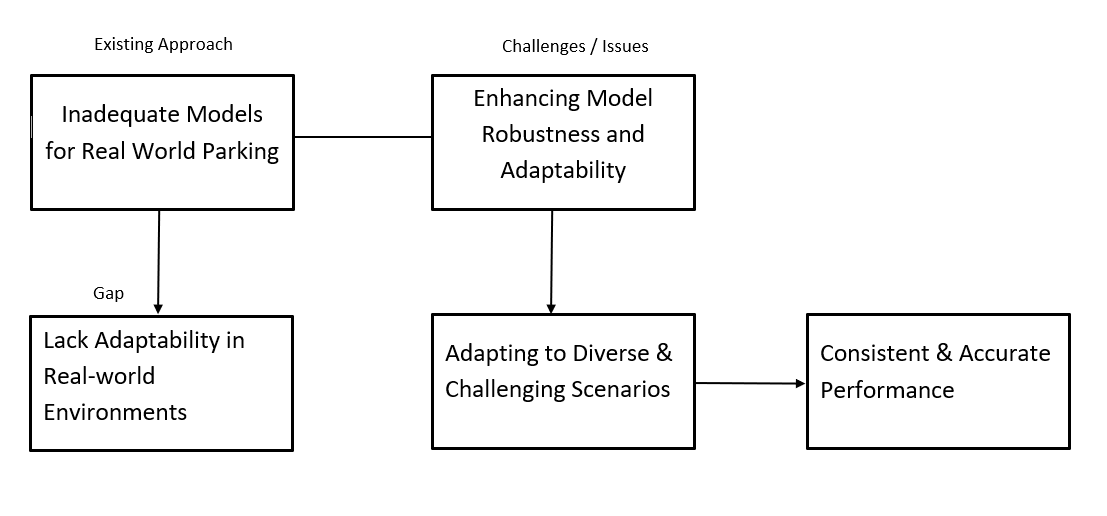


Figure 11. Challenges of Parking Lot Scenarios

* + 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.

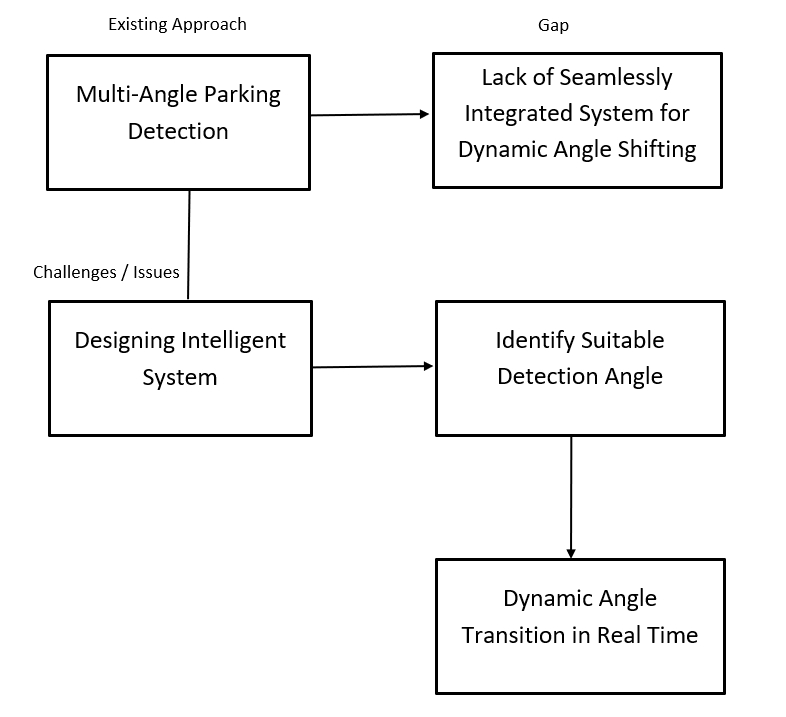


Figure 12. Challenges of Multi-Angle Parking Detection

* + 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.

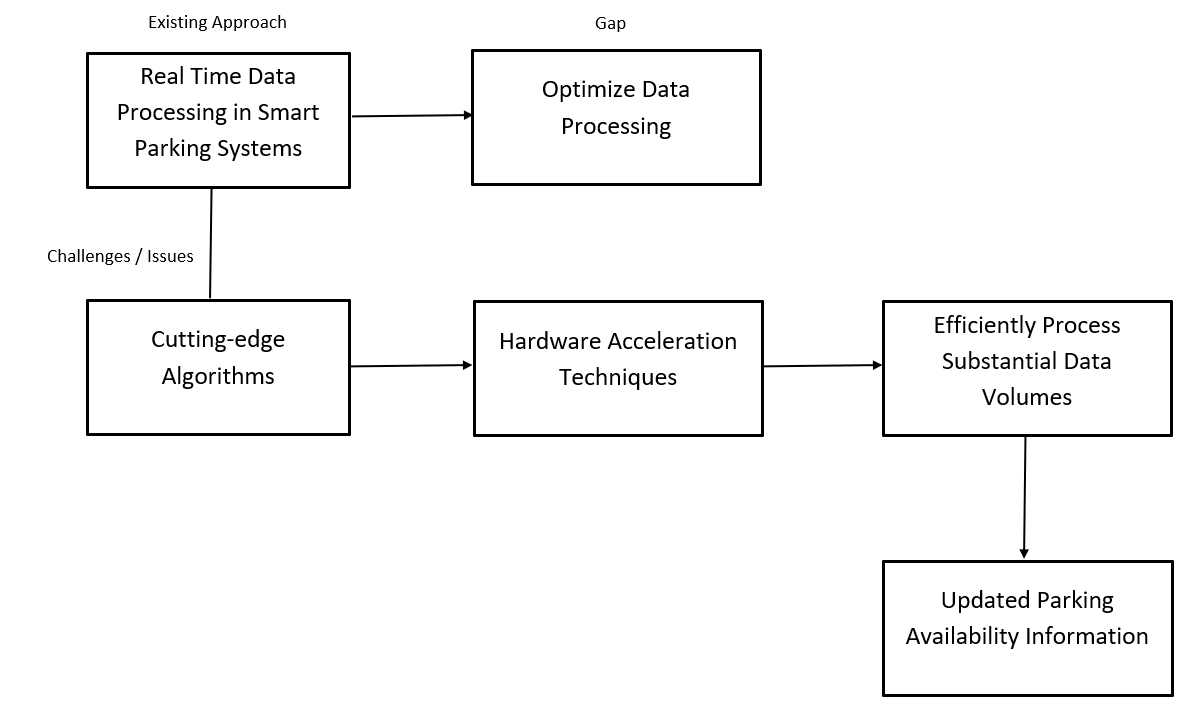


Figure 13. Challenges in Real Time Data Processing and Decisoin Making in Parking Systems

* + 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.

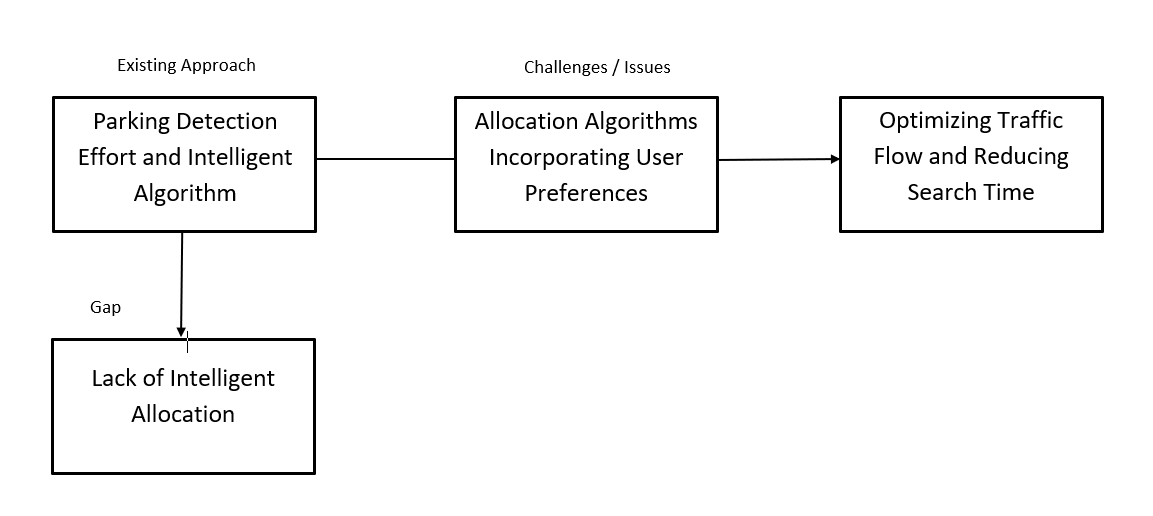


Figure 14. Challenges in Dynamic Parking Allocation

* + 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.

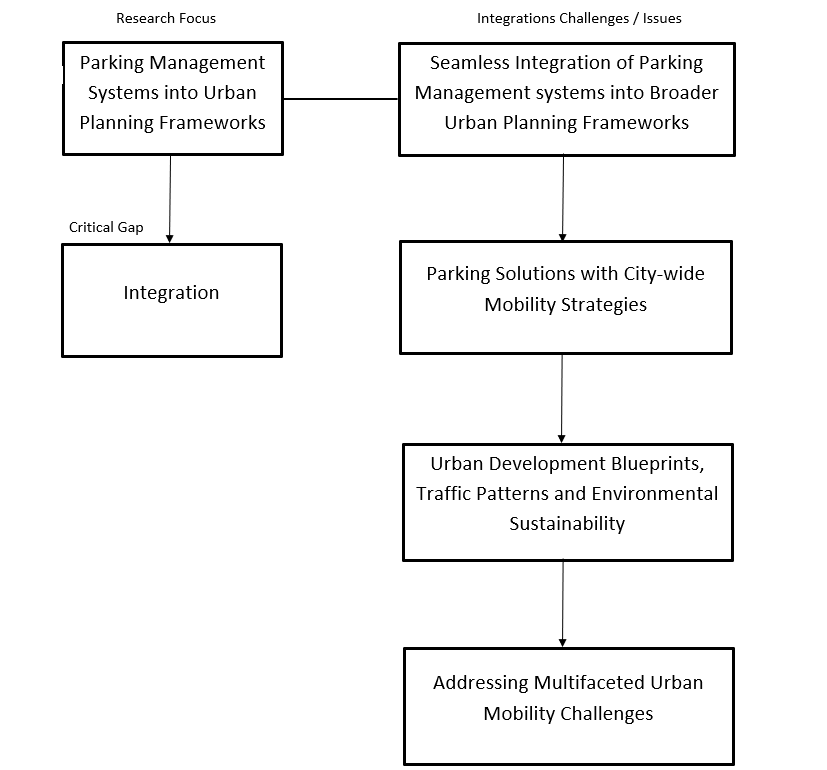


Figure 15. Challenges of Integration with Urban Planning

* + 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.

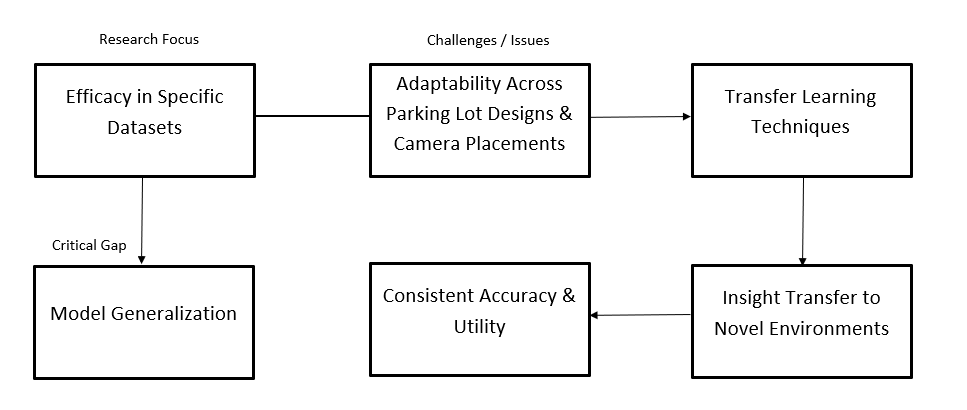


Figure 16. Challenges of Model Generalization across Diverse Parking Lots

* + 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.

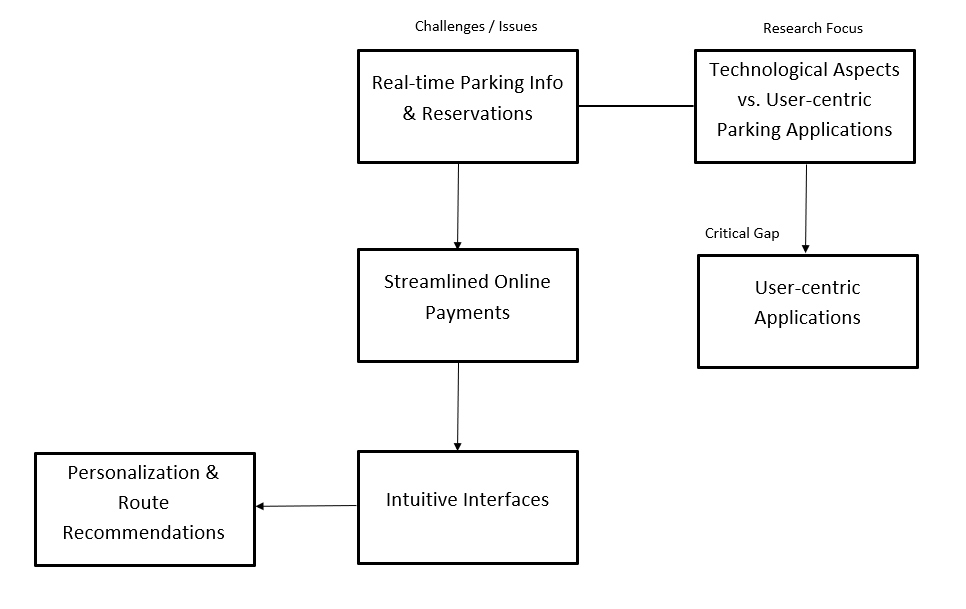


Figure 17. Challenges of Crafting User-Centric Applications with Parking Management Systems

* + 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.

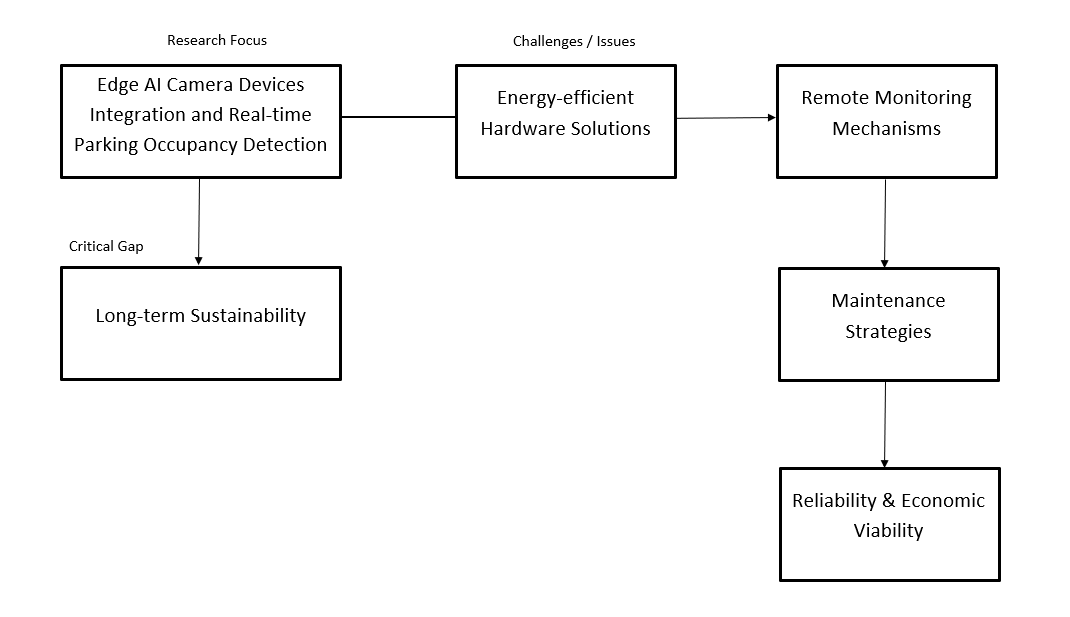


Figure 18. Challenges of Long-Term System Sustainability in Parking Systems

## 1.4 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.

## 1.5 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?

## 1.6 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

**1.7.1 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 research's technical facets delve into a comprehensive approach for efficient parking management. The initial phase revolves around object detection, a pivotal process for monitoring incoming vehicles. Surveillance cameras strategically positioned within the parking area capture high-quality images of vehicles as they enter. These images undergo a meticulous image processing procedure, employing advanced techniques like Optical Character Recognition (OCR) and specialized license plate recognition (LPR). Through these methods, the system successfully extracts characters from license plates, enabling accurate identification of each vehicle. To bolster accuracy, the system integrates with external databases, cross-referencing license plate data with vehicle type information from third-party sources. This dual verification mechanism significantly enhances security, guaranteeing the precise recognition of various vehicle types upon entry.

In instances where vehicles have been previously vetted, the system leverages localized databases to expedite the process. This optimization eliminates the need for extensive server-side requests, ensuring a rapid and efficient procedure for recognized vehicles. As a result, potential delays are mitigated, and the entry experience for returning visitors is markedly improved. The system seamlessly compiles the pertinent details of each recognized vehicle, including ownership information, which is then seamlessly relayed to the Parking Manager Agent for streamlined cost and duration management, ensuring an all-encompassing and technologically advanced parking solution.

Object Detection, initiates research by focusing on discerning and categorizing incoming vehicles, specifically with an emphasis on identifying cars. As vehicles enter the parking area, specialized surveillance cameras capture images of their license plates. These images are then processed on a local server using sophisticated image processing techniques. The server adeptly identifies edges within the images, proceeding to segment characters and extract license plate numbers. Through integration with a third-party database or API linked to government agencies, the system accurately deciphers these numbers, classifying vehicles and obtaining ownership information. This verified data is meticulously stored within a local database, streamlining future entry procedures and facilitating accurate record-keeping for enforcement purposes.

The Monitoring takes center stage as the Parking Manager assumes a pivotal role. This phase encompasses various critical responsibilities that contribute to efficient parking management. Firstly, the Parking Manager compiles comprehensive profiles of car owners, capturing essential details from license plate numbers, such as names, CNIC numbers, contact information, and addresses. It meticulously manages vehicle-related information, including license plate numbers, car models, and engine details, all captured by surveillance cameras during the object detection phase. The Parking Manager also maintains an organized record of parking fees, supporting customizable fee structures based on time. Additionally, it monitors the duration of each vehicle's stay, ensuring compliance with parking regulations. Furthermore, the Parking Manager actively monitors parking slot availability, receiving real-time updates through surveillance cameras, which capture parking slot images for accurate occupancy status.

The Allocation of Parking Slot introduces an interactive approach to parking slot assignment. Users engage through a dedicated mobile application, visualizing available and occupied slots intuitively. Within a designated time, frame, users select preferred slots, and if not, the Parking Manager autonomously allocates based on proximity. Surveillance cameras verify these selections and guide users using navigational-like instructions via the mobile app, ensuring a seamless parking experience.

The system accommodates scenarios where users vacate slots prematurely, triggering reallocation notifications or guidance. If slots are available, the Parking Manager efficiently reallocates the nearest slot and notifies users. When all slots are occupied, users are directed to exit and re-enter when space becomes available.

The integration of these modules culminates in a comprehensive system architecture, seamlessly merging object detection, agent monitoring, and parking slot allocation. Employing advanced image processing techniques, local server capabilities, and an intuitive mobile app, this methodology addresses prior limitations, offering innovative solutions for parking occupancy prediction, precise record-keeping, and efficient space utilization. Leveraging technologies like Python, Keras, TensorFlow, and GPU resources enhances the project's potential for effective implementation.

**1.7.2 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.

The research methodology comprises a series of interconnected modules, each playing a vital role in achieving a holistic solution. These modules collectively tackle the complexities associated with parking occupancy prediction, object detection, and streamlined parking management.

# **2.** **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.

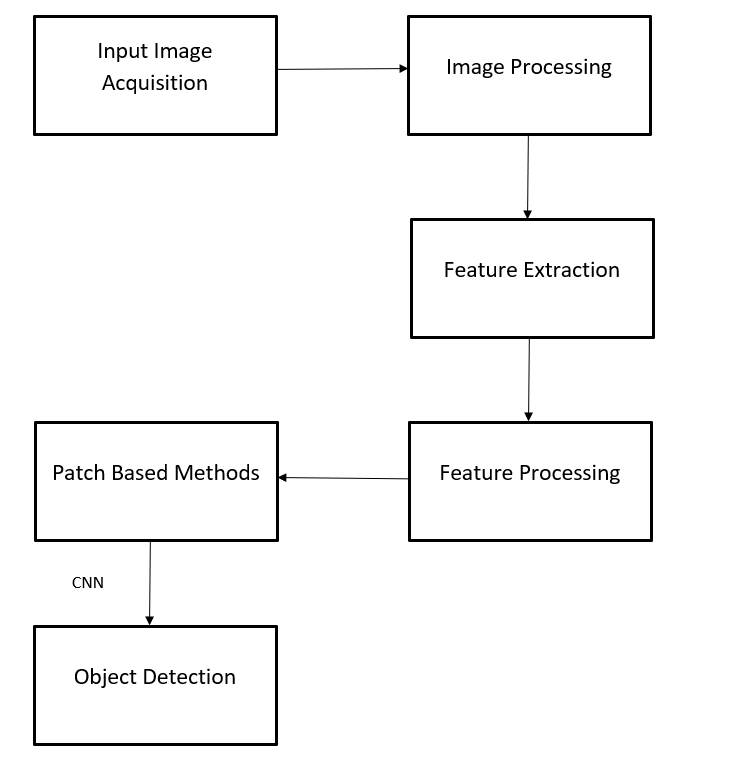


Figure 19. Deep Learning Advancements in Parking Space Detection

## 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.

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.

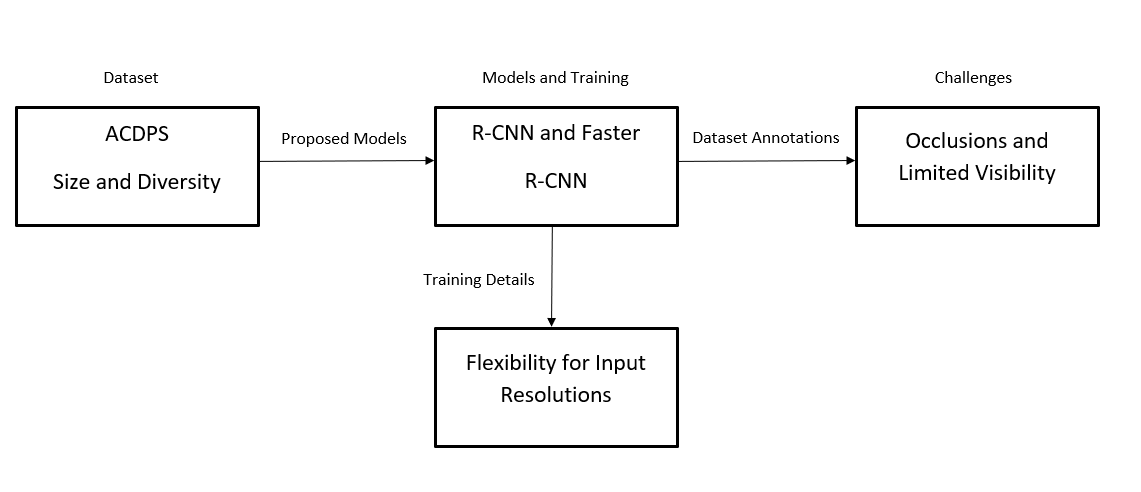


Figure 20. Summary of Image-Based Parking Space Occupancy Classification Research

## 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, Madurawe, Abeysinghe 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, Madurawe, Abeysinghe 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).

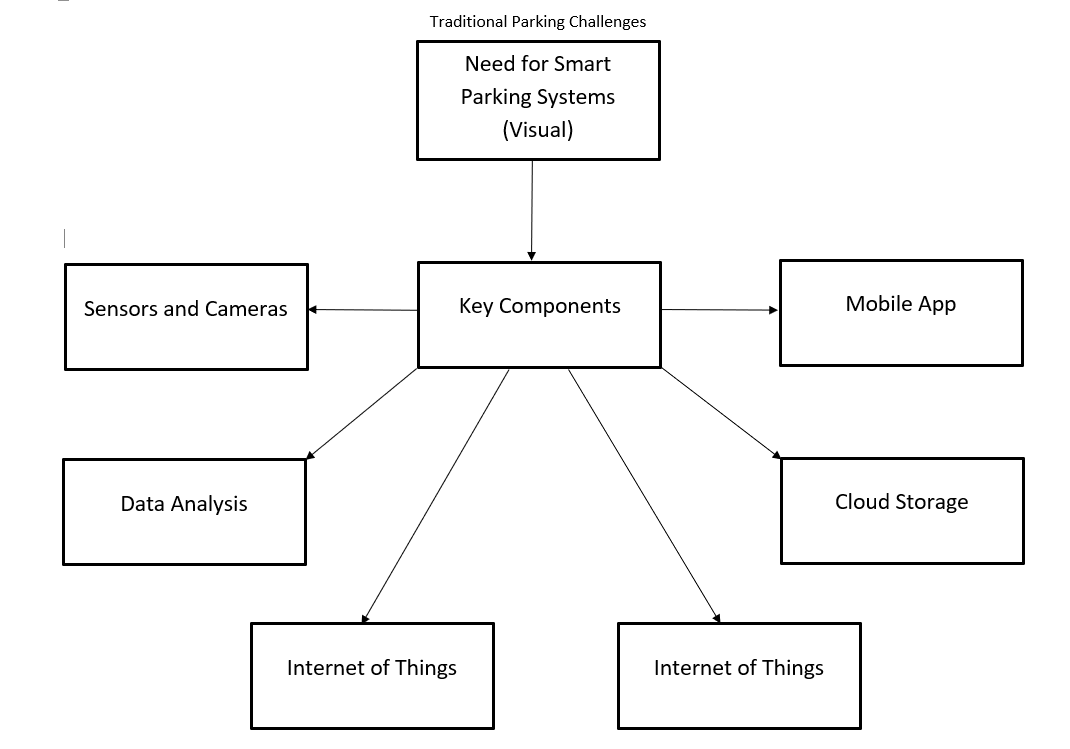


Figure 21. Revolutionizing Urban Parking: A Visual Overview

## 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.

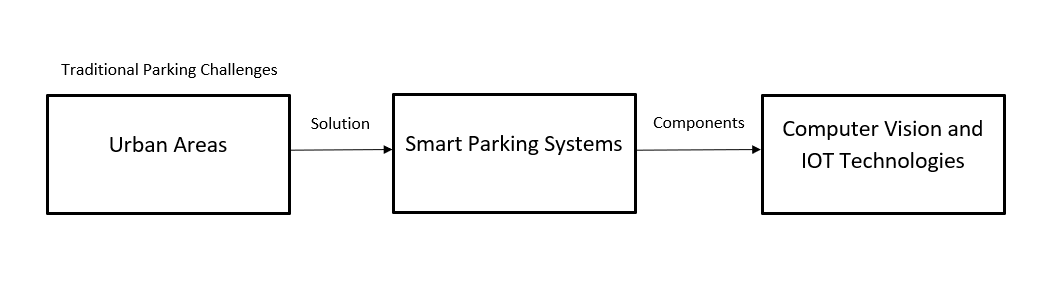


Figure 22. Evolution of Parking Management: From Traditional Challenges to Smart Solutions

## 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.

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.

## 2.7 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.

# **3.** **Proposed Methodology**

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.

## 3.1 Introduction to Research Methodology

The research methodology devised for this study is aimed at systematically addressing the intricate challenges highlighted in the research introduction. The focus is on tackling the shortage of parking spaces in closed deterministic environments by developing an innovative Smart Parking Management System that incorporates cutting-edge image processing techniques, IoT technology, and cloud-based solutions.

The chosen research design combines qualitative and quantitative approaches to effectively explore the multifaceted research objectives. By doing so, it bridges the gap between theoretical principles and practical applications, aligning with the pragmatic philosophy. This approach recognizes that the integration of theoretical insights and real-world applications is vital in dealing with the complexities of parking occupancy prediction and object detection challenges.

In terms of data collection, a dual-strategy is employed. Qualitative data is gathered through in-depth interviews with experts from relevant fields, providing nuanced insights into the specifics of parking challenges. Simultaneously, observational data is acquired by closely observing real-life parking scenarios in closed deterministic environments. This qualitative approach offers a deeper understanding of user behavior and contextual intricacies.

On the quantitative front, the research methodology involves creating a meticulously curated dataset of parking lot images. Surveillance cameras capture images across various lighting conditions, replicating the challenges encountered in real closed deterministic environments. Alongside this, metadata is collected through a mobile application, capturing parking duration, occupancy status, and user interactions. This quantitative data empowers the empirical evaluation of the proposed solution's effectiveness.

The data analysis phase encompasses thematic analysis for qualitative data and comparative assessment for quantitative data. Thematic analysis involves identifying common themes and patterns within the expert interviews and observational data. This qualitative approach contributes contextual insights and informs the development of the Smart Parking Management System. Concurrently, quantitative data is subject to rigorous experiments to compare state-of-the-art deep learning architectures such as vision transformers and CNNs. The goal is to quantify their performance across diverse visual scenarios.

Ethical considerations play a crucial role throughout the research methodology. Measures are taken to ensure informed consent and confidentiality during interviews with experts. Privacy concerns associated with image data are addressed through anonymization and adherence to data protection regulations. The integration of IoT and cloud-based components emphasizes data security and user privacy, aligning with ethical guidelines.

It's essential to acknowledge the limitations inherent in this methodology. Qualitative analysis might introduce subjectivity, and controlled quantitative experiments may not fully capture the complexities of real-world scenarios. Awareness of these limitations guides the interpretation of findings and reinforces the credibility of the research.

The research methodology expertly blends qualitative insights and quantitative rigor to develop solutions for parking space scarcity. It sets the stage for achieving research objectives, and subsequent sections will delve into specific modules that form a cohesive research methodology. This comprehensive approach aims to advance the field of parking management and provide innovative solutions to the challenges at hand.

## 3.2 Research Design

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 primary objective is to establish an efficient and accurate object detection system with a specific focus on identifying vehicles, particularly cars, as they enter the designated parking area. This intricate process involves a series of carefully orchestrated steps aimed at seamlessly managing the entire process of vehicle identification and validation.

Firstly, surveillance cameras are strategically positioned at the entrance of the parking facility to ensure optimal coverage for capturing high-quality images of incoming vehicles. These captured images then undergo meticulous analysis through advanced object detection algorithms, which accurately determine whether the object in question is indeed a car. Once confirmed as a car, the system proceeds to extract critical details, including the license plate number.

The subsequent stages involve local server processing, where the captured image and the extracted license plate information are swiftly transmitted to a dedicated local server for further comprehensive processing. Here, a sequence of image processing techniques is employed to precisely isolate and delineate the edges of the detected vehicle within the image. This meticulous process paves the way for effective character segmentation, wherein the characters on the license plate are methodically extracted and prepared for subsequent recognition.

To ensure the credibility of the identified vehicle, the segmented license plate is subjected to thorough cross-referencing with a trusted third-party database or API that maintains an authoritative record of government excise and taxation information. This verification process serves as a crucial step in confirming the authenticity of the vehicle. In the event of successful validation, the pertinent ownership details of the vehicle are seamlessly retrieved.

To facilitate seamless administration and future reference, the system maintains a comprehensive local database. This repository includes essential information about verified vehicles, encompassing their license plate numbers, associated ownership details, and precise entry timestamps. The cumulative data serves as a vital foundation for maintaining meticulous records and enforcing necessary penalties in cases of parking rule violations.

In essence, the amalgamation of these meticulously executed steps enables the establishment of a robust and highly effective object detection system tailored specifically for vehicle identification within the designated parking area. The seamless integration of cutting-edge technology and systematic processes ensures accurate verification of vehicles and meticulous record-keeping, contributing to enhanced parking management and enforcement practices.

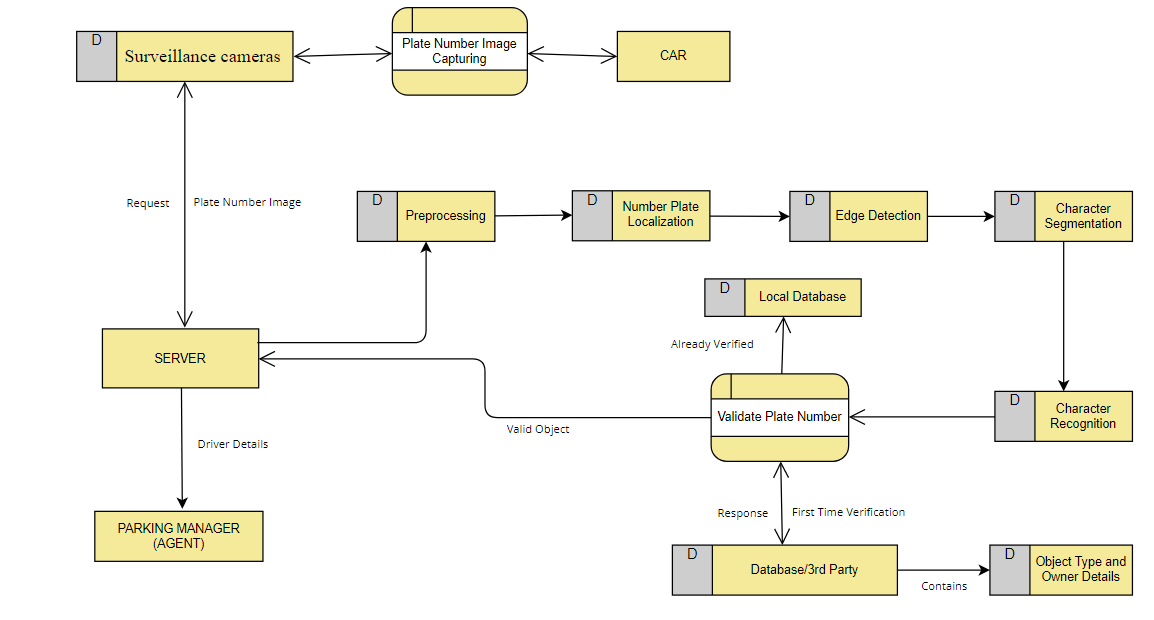


Figure 23. Object Detection Architecture Design

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

In the second phase of the project, the pivotal role of the Parking Manager comes into focus, encompassing a multifaceted array of responsibilities related to the seamless operation of the parking area and interactions with users. At the core of these responsibilities lies the extraction of essential driver information from the license plate data, including crucial details such as the driver's name, CNIC number, mobile number, and address. Simultaneously, the system diligently collects comprehensive vehicle information, encompassing the license plate itself, the specific car model, and the engine number.

Integral to the Parking Manager's role is the meticulous management of parking fee details. This involves the maintenance of an exhaustive record that affords the flexibility to customize parking fees based on an array of factors. This encompasses an intricate framework of hourly rates, penalties for instances exceeding designated time limits, and any supplementary charges that may be applicable.

A critical facet of the Parking Manager's responsibilities lies in the precise tracking of parking durations for each occupied slot. By calculating the temporal interval between a vehicle's entry into the parking area and its subsequent exit, the system seamlessly computes the exact duration for which a parking slot is utilized. This information proves to be invaluable for accurate fee calculations and efficient slot turnover.

The meticulous oversight of parking slot details constitutes yet another core aspect of the Parking Manager's responsibilities. By leveraging the continuous monitoring capabilities of the surveillance cameras, the Parking Manager adeptly manages the real-time occupancy status of parking slots. These ongoing surveillance efforts translate into timely updates regarding the availability and occupancy of individual parking slots, contributing to effective management of parking resources.

In the realm of user communication and adherence to parking regulations, the Parking Manager shoulders the responsibility of issuing notifications. These notifications are strategically dispatched to users in cases where parking rules are breached, time limits are exceeded, or payment for parking is required. This proactive approach not only contributes to enhanced user compliance but also fosters a harmonious parking environment.

Collectively, the second phase of the project underscores the indispensable role of the Parking Manager in orchestrating a harmonious and efficiently managed parking area. Through the comprehensive extraction of driver and vehicle information, meticulous fee management, precise duration tracking, real-time slot occupancy management, and proactive user notifications, the Parking Manager's contributions play a pivotal role in optimizing the overall parking experience and fostering adherence to parking regulations.

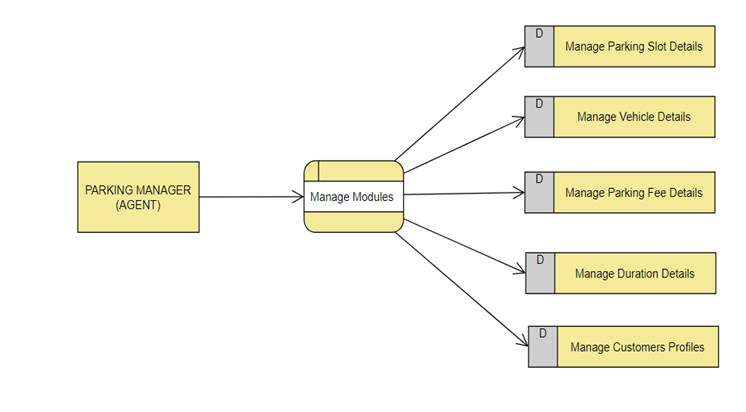


Figure 24. Monitoring Architecture Design

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

The final phase of the project centers around enhancing the efficiency of parking slot allocation and reallocation to achieve optimal utilization of available parking space. To facilitate this seamless process, a user-friendly mobile application takes center stage, providing users with an interactive platform that empowers them to request parking slots, view the current availability of slots, and engage with the system in a convenient manner.

Within this phase, the strategic allocation of parking slots plays a pivotal role. Users are granted the autonomy to handpick their desired parking slots within a predefined time window via the mobile app. In cases where users neglect to perform slot selection, the onus is transferred to the capable hands of the Parking Manager. Utilizing advanced image processing techniques on images of available parking slots, the Parking Manager meticulously assesses and assigns the most suitable slot for the user, ensuring a harmonious alignment between preferences and practicality.

The principle of efficient space utilization extends to the concept of slot reallocation. When a user vacates their assigned parking slot, the Parking Manager promptly undertakes the task of reallocating the now-available slot to other users. This dynamic process fosters a continuous cycle of slot optimization and resource maximization.

In situations where parking slots become temporarily unavailable due to high demand, the system promptly informs users of the constraints. Users are promptly advised to exit the parking area and consider reentering at a more opportune time, ensuring a transparent and accommodating experience.

To facilitate seamless slot turnover, users are required to notify the system when they are vacating their allocated parking slots. This process can be executed manually via the mobile app or triggered automatically through a predetermined timeout mechanism, ensuring that slots are efficiently released for subsequent users.

The implementation of reminder notifications further bolsters the efficiency of parking slot management. In scenarios where users fail to relinquish their parking slots within a specific duration, automated reminders are dispatched. These reminders can be delivered through the mobile app itself, SMS, or email, providing users with gentle nudges to maintain a steady flow of slot turnover.

The final phase of the project culminates in the establishment of a sophisticated parking slot allocation and reallocation system that prioritizes optimal space utilization. Through the user-friendly mobile application, strategic slot allocation, dynamic reallocation processes, efficient handling of slot unavailability, streamlined slot vacation notifications, and timely reminder dispatches, the system orchestrates a harmonious and resourceful parking experience that caters to user preferences while maximizing the utility of available parking space.

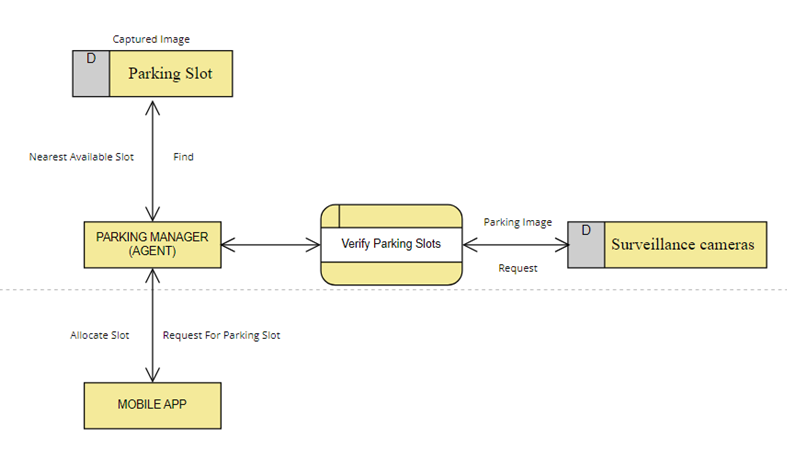


Figure 25. Architecture Design of Slot Allocation by Parking Manager

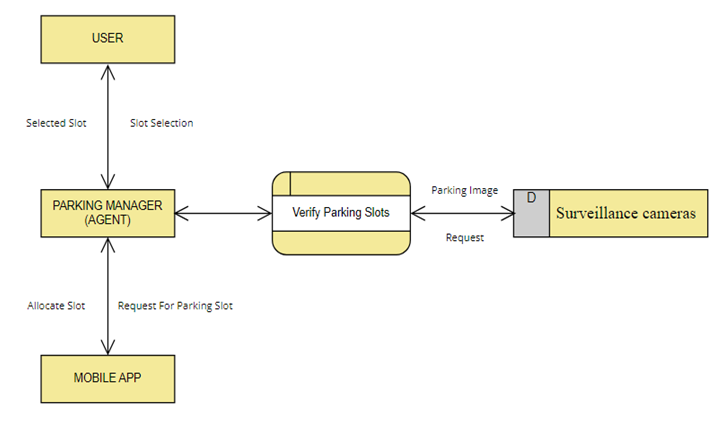
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Figure 26. Architecture Design of Slot Allocation by User

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.

**3.2.4 System Architecture**

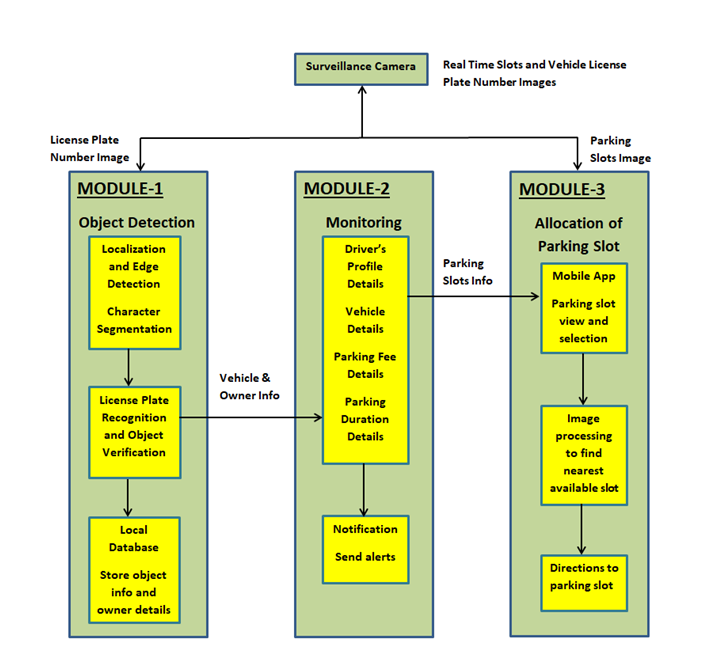


Figure 27. System Architecture Design

## 3.2.5 Proposed Model

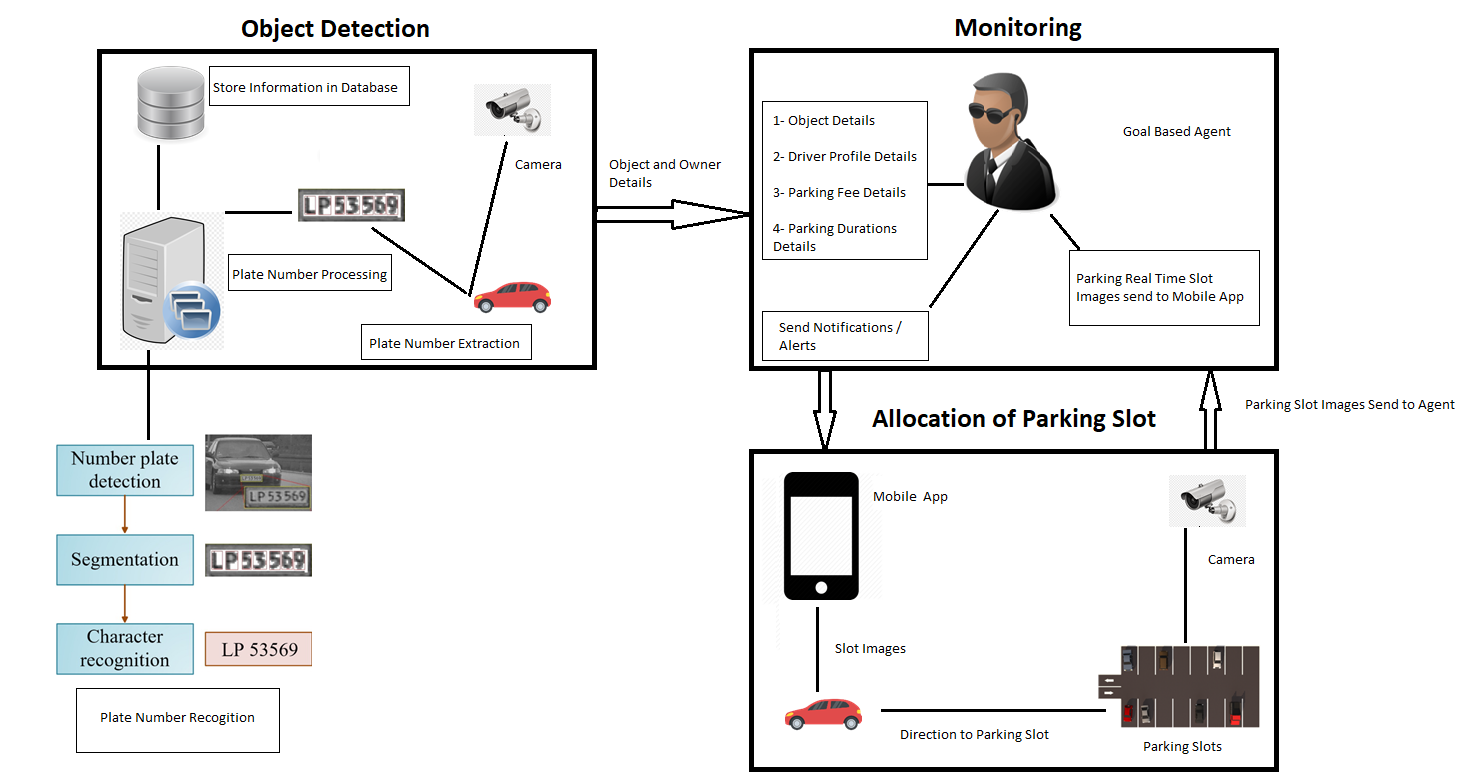


Figure 28. Proposed Model for Object Detection and Parking Occupancy Prediction

## Research Philosophy and Approach

The research philosophy and approach adopted for this study are strategically devised to systematically address the intricate challenges outlined in the research introduction. The central objective is to tackle the persistent shortage of parking spaces within confined deterministic environments. This is to be accomplished by crafting a pioneering Smart Parking Management System, seamlessly integrating cutting-edge image processing techniques, IoT technology, and cloud-based solutions.

The chosen research design harmoniously merges both qualitative and quantitative methodologies, forging an effective path to explore the multifaceted research objectives. This approach effectively bridges the gap between theoretical underpinnings and real-world implementations, aligning harmoniously with a pragmatic philosophy. This approach acknowledges that marrying theoretical insights with practical applications is essential in navigating the intricate complexities of predicting parking occupancy and addressing object detection challenges.

In the realm of data collection, a dual-pronged strategy is employed. Qualitative data is meticulously gathered through in-depth interviews with experts in relevant fields, extracting nuanced insights into the granular details of parking challenges. Concurrently, observational data is meticulously acquired by closely monitoring real-life parking scenarios within closed deterministic environments. This qualitative approach empowers a deeper understanding of user behaviors and contextual intricacies that influence parking dynamics.

On the quantitative front, the research methodology meticulously assembles a curated dataset of parking lot images. Surveillance cameras are strategically positioned to capture images under varying lighting conditions, effectively mirroring the challenges encountered in real-world closed deterministic environments. Complementary metadata is collected through a dedicated mobile application, capturing key variables such as parking duration, occupancy status, and user interactions. This quantitative data serves as the bedrock for the empirical assessment of the proposed solution's efficacy.

In the subsequent data analysis phase, thematic analysis is meticulously employed for qualitative data, systematically identifying recurring themes and patterns embedded within expert interviews and observational data. This qualitative dimension adds a contextual layer of insights that informs the development of the Smart Parking Management System. Concurrently, quantitative data undergoes rigorous experimentation, involving the comparison of cutting-edge deep learning architectures, including vision transformers and convolutional neural networks (CNNs), across diverse visual scenarios. The ultimate aim is to quantitatively assess their performance and capabilities.

Ethical considerations are meticulously threaded throughout the research methodology. Stringent measures are in place to ensure informed consent and the utmost confidentiality during interviews with experts. Privacy concerns linked to image data are effectively mitigated through anonymization techniques and strict adherence to prevailing data protection regulations. The incorporation of IoT and cloud-based components underscores the paramount importance of data security and user privacy, aligning impeccably with ethical guidelines.

The research methodology candidly acknowledges the inherent limitations in its design. Qualitative analysis might introduce subjective interpretations, while controlled quantitative experiments may not fully capture the intricate nuances of real-world scenarios. The researchers' awareness of these limitations serves as a compass for interpreting findings and bolsters the credibility of the research outcomes.

Collectively, this research methodology adeptly synthesizes qualitative insights and quantitative rigor to devise innovative solutions for the challenge of parking space scarcity. This comprehensive approach sets the stage for achieving the research objectives, and the subsequent sections delve into the intricacies of specific modules that cohesively shape the overarching research methodology. The ultimate aspiration is to propel the field of parking management forward, introducing pioneering solutions to the pressing challenges at hand.

## 3.4 Research Strategy

## The research strategy employed in this study is strategically designed to systematically address the multifaceted challenges outlined in the research introduction. The primary aim of the research strategy is to provide a coherent roadmap for investigating the intricate complexities of parking space scarcity within closed deterministic environments. Through a meticulously crafted approach that amalgamates various methodologies, the research strategy aligns harmoniously with the overarching research philosophy and objectives.

## At its core, the research strategy focuses on the development and validation of an innovative Smart Parking Management System. This system is envisioned to seamlessly integrate cutting-edge image processing techniques, IoT technology, and cloud-based solutions to effectively mitigate the shortage of parking spaces. The research strategy encompasses multiple interconnected components, each contributing uniquely to the holistic investigation.

## To realize the research objectives, a multifaceted research design is embraced, skillfully combining both qualitative and quantitative methodologies. This duality allows for a comprehensive exploration of the research challenges, harmonizing theoretical principles with practical implementations. The pragmatic philosophy underlying this approach recognizes the significance of bridging the gap between abstract concepts and real-world applications.

## The data collection phase forms a pivotal aspect of the research strategy. It is orchestrated using a dual-strategy approach that synergistically harnesses qualitative and quantitative data. Qualitative data is diligently amassed through in-depth interviews with experts, extracting rich insights into the nuanced dimensions of parking challenges. This qualitative dimension is complemented by observational data acquired through the close monitoring of real-life parking scenarios in closed deterministic environments. This meticulous approach ensures that both the human and contextual aspects of parking dynamics are comprehensively captured.

## On the quantitative front, the research strategy meticulously constructs a dataset of parking lot images, incorporating variations in lighting conditions to emulate real-world challenges. This quantitative data is complemented by metadata collected through a mobile application, encompassing vital variables such as parking duration, occupancy status, and user interactions. This dataset acts as a cornerstone for the empirical evaluation of the proposed Smart Parking Management System's effectiveness.

## The data analysis phase elegantly integrates thematic analysis for qualitative data and a comparative assessment for quantitative data. Thematic analysis systematically identifies recurring themes and patterns within expert interviews and observational data, fostering contextual insights that guide the development of the solution. Concurrently, the quantitative data undergoes rigorous experiments, involving the evaluation of advanced deep learning architectures like vision transformers and CNNs. The aim is to quantitatively gauge their performance across diverse visual scenarios.

## Throughout this research strategy, ethical considerations stand as an unwavering pillar. Measures are diligently implemented to uphold informed consent and maintain the utmost confidentiality during expert interviews. Privacy concerns associated with image data are meticulously addressed through anonymization techniques and adherence to data protection regulations. The integration of IoT and cloud-based components further underscores the priority placed on data security and user privacy, ensuring alignment with ethical guidelines.

## While acknowledging the inherent limitations, the research strategy expertly navigates these challenges. It is the cornerstone that orchestrates the synthesis of qualitative insights and quantitative rigor, leading to innovative solutions for parking space scarcity. By setting a comprehensive stage for research objectives, the research strategy serves as the guiding force in advancing the field of parking management and offering groundbreaking solutions to the complex challenges.

## 3.5 Data Collection Methods

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."

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.

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.

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.

* + 1. **Data Collection**

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 parking lot images from various sources, each showcasing distinct visual conditions and environmental scenarios. The data collection process required several publicly available parking lot occupancy datasets are considered for this research, each with its strengths and limitations. The selection involves identifying datasets encompassing a wide range of visual conditions, weather scenarios, and occlusions to ensure system robustness and generalization ability. The chosen datasets include.

**3.5.1.1 PKLot**

This Dataset contains 12,417 images captured under different weather conditions. It is limited by minimal occlusions due to camera positioning.

**3.5.1.2 ACMPS**

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

**3.5.1.3 CNRPark**

This dataset provides a closer view of parked cars, includes labels for various weather conditions, and presents extra occlusions between cars and other objects.

**3.5.1.4 ACPDS**

Despite being the smallest dataset, ACPDS offers a high number of unique viewpoints and visual categories. It introduces challenges due to perspective distortions from wide-angle camera setups.

**3.5.1.5 SPKL**

This dataset, collected by the research team, addresses the lack of wintertime images in existing datasets, featuring 440 images with varying snow conditions.

The extracted images and corresponding labels from each dataset are collected and standardized. Annotations of parking lots from different datasets are converted into a unified format, verified for consistency and accuracy, and then split into training, validation, and testing sets.

To increase the diversity of training data, image augmentation techniques are applied, including rotation, flipping, resizing, and brightness adjustments.

To address specific visual conditions not well-represented in existing datasets, labels associated with each dataset are extended up to 11 categories, accommodating scenarios like fog, night, glare winter as shown in Table 1. The selected object detection algorithm is EfficientNet-B03, chosen for its lightweight and efficient performance. The architecture is customized with depth-wise convolutions, swish activation, and squeeze & excitation subblocks. Transfer learning is applied to fine-tune the architecture for parking occupancy detection using the collected datasets.

The training phase involves loading preprocessed datasets, creating data loaders for efficient training, and training the EfficientNet-B03 model on the training set using binary cross-entropy as the loss function. Hyperparameter tuning explores learning rates, batch sizes, and regularization techniques.

The integration of location awareness involves creating 3D representations of parking environments using available location data (e.g., GPS coordinates). Location-based slot allocation optimizes parking slots based on real-time occupancy predictions and available parking spaces.

The development of an Intelligent Parking Manager Agent employs reinforcement learning techniques, utilizing algorithms like Deep Q-Network (DQN) for real-time adaptation to changing parking patterns and dynamic slot reallocation.

A user-friendly mobile application is designed with an intuitive interface, allowing users to interact with the system, view real-time parking availability, and receive notifications about their allocated slots and penalties. The mobile application is integrated with the Real-Time Car Parking Occupancy Prediction System to provide real-time updates.

Performance evaluation involves assessing the model's accuracy, precision, recall, F1 score, and area under the ROC curve on validation and test datasets. System evaluation evaluates the overall performance of the Real-Time Car Parking Occupancy Prediction System in improving illumination, optimizing parking allocation, and enhancing cost efficiency.

The results are analyzed and interpreted to draw conclusions about the system's efficacy, taking into consideration data analysis techniques, ethical considerations, validity, reliability, and the research timeline.

Table 1. Description of datasets regarding different types of visual conditions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Dataset** | PKLot | CNRPark | ACPDS | ACMPS | SPKL |
| **Total Images** |  |  |  |  |  |
| Sunny  Overcast  Rainy  Winter  Fog  Glare  Night  Infrared  Occlusion (car)  Occlusion (tree)  Distortion |  |  |  |  |  |

# **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.

## 4.1 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.

**4.3.6 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.

# **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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