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*Original article*

# Deep Learning-Based Vehicle Parking Occupancy Detection

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**Abstract**
In urban locations, effective parking management is essential to reducing traffic and improving mobility in general. The increasing need for precise, real-time parking space monitoring has not been satisfied by conventional techniques of vehicle parking occupancy detection, such as human counting and sensor-based systems. This research proposes a deep learning-based approach for vehicle parking occupancy detection, leveraging convolutional neural networks (CNNs) and transfer learning techniques. In this study, we provide a system for tracking and analyzing the occupancy of the parking lots at the National Commercial Bank's (NCB) main building in real time. The technique combines image analysis with deep learning. In order to monitor each parking space independently, we specifically use YOLO (You Only Look Once) as a deep learning model for object detection and OpenCV for image analysis to determine the coordinates of each parking slot. This study aims to optimize the use of parking areas and to reduce the time wasted by daily drivers to find the right parking slot for their cars. Also, it helps to better manage the space in the parking areas. The inference model was used to evaluate the accuracy of the model on custom data collected from actual parking lot environments. This evaluation confirmed the model's effectiveness in handling real-world data and achieving high performance in parking space occupancy detection, enhancing the system's reliability for practical use. The proposed system achieves very good accuracy, outperforming traditional methods
**Keywords**. Deep Learning, Image Analysis, Parking Lots, Transfer Learning, YOLO.

## Introduction

The rapid development of artificial intelligence (AI) has revolutionized our ability to address various urban challenges, including efficient parking space management. In Libya, the continuous rise in vehicle numbers has exacerbated traffic congestion, prolonged parking search times, and heightened environmental concerns. Traffic jams not only disrupt daily life but also result in increased pollution levels, longer travel durations, and economic losses caused by delays and inefficiencies in urban mobility [1]. An intelligent car park space allocation system aims to tackle these challenges by optimally assigning available parking spots to incoming vehicles. Effective parking solutions can lead to improved traffic flow, enhanced user experiences, and greater environmental sustainability. Researchers have explored a variety of approaches to address the parking allocation problem, including mathematical optimization models, deep learning techniques, and real-time decision-making systems. These systems commonly rely on sensors, cameras, and software applications to monitor parking space availability in real-time. In this research, we leverage state-of-the-art deep learning models to automate the detection of vacant parking spaces at the NCB main building's car park. The system will utilize pre-installed surveillance cameras and existing digital screens in the parking area, ensuring minimal implementation costs. Furthermore, the proposed system is highly scalable and can be seamlessly integrated into other organizations' automated car park management systems.

Efficient vehicle parking management has become a critical challenge in urban environments due to increasing vehicle numbers, limited parking spaces, and rising environmental concerns. Over time, various approaches have been developed to address this issue. This literature review categorizes existing research into three main themes: Traditional Parking Detection Techniques, Emergence of Computer Vision in Parking Systems, and Deep Learning in Parking Occupancy Detection.

Before the advent of advanced technologies, traditional car parking methods relied heavily on manual processes and human intervention such as: Parking Attendants guiding drivers to available spaces. Signage and Markings that simple signs and painted markings on the ground directed drivers to available parking spaces and designated areas, these methods are time-consuming, labor-intensive, and subject to human mistakes. Another method is Sensor-Based Systems, early parking detection systems primarily relied on sensor networks, including ultrasonic sensors, infrared sensors, and magnetic field sensors to detect the occupancy of parking spaces. These sensors were typically installed in individual parking spots to monitor availability [2] ,But it required a high installation and maintenance costs, scalability challenges in large parking lots. RFID and IoT- Based Approaches: The use of Radio Frequency Identification (RFID) tags and Internet of Things (IoT) systems has facilitated better parking management through real-time data exchange and remote monitoring [3],its main limitation its dependency on RFID-enabled vehicles; coverage issues in dense urban environments. Also, a Rule-Based Algorithms and Static Optimization Models where mathematical models and heuristic algorithms used to optimize parking allocation and reduce search time.


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Techniques like linear programming have been widely applied [4] the main limitations of these models are the lack of adaptability in dynamic and unpredictable parking scenarios.
The car park space allocation problem has become an increasingly important area of research, driven by the need to efficiently manage limited parking resources in urban environments. In recent years, the application of deep learning techniques has emerged as a promising approach to address the complexities and dynamic nature of this problem. One of the early studies in this domain was conducted by Geng and Cassandras [5] proposed a deep learning-based framework that combined a CNN for occupancy prediction with a mixed-integer programming model for space allocation
Deep learning and transfer learning have emerged as transformative approaches in addressing the complexities of modern parking systems. Deep learning, a subset of artificial intelligence (AI), utilizes multi-layered neural networks to model and interpret complex patterns within large datasets. In the realm of computer vision, deep learning algorithms enable machines to process, analyze, and understand visual data such as images and videos with unparalleled accuracy. This capability has revolutionized computer vision applications [6] [7], allowing for significant advancements in fields ranging from facial recognition to medical imaging.
In the context of car parking systems, deep learning algorithms are applied to a variety of tasks, including vehicle detection, license plate recognition, and parking space availability prediction. These algorithms can process real-time data from surveillance cameras to provide accurate and timely parking status updates, significantly enhancing the efficiency and reliability of parking allocation systems. Complementing this, Transfer learning is a powerful technique in machine learning and deep learning that leverages a pretrained model originally developed for one task and repurposes it for a different yet related task. This approach is particularly advantageous when limited labeled data is available for the target task. By transferring knowledge gained from large-scale datasets, transfer learning reduces both training time and computational requirements, while often improving overall model performance.
In the context of car parking systems, transfer learning can be utilized to adapt models trained on extensive datasets of urban traffic and parking scenarios to specific parking lots or facilities [8] . This adaptation ensures that the models remain effective in varying environmental conditions and structural layouts, ultimately improving the adaptability and scalability of parking management systems.
This study aims to address the car park space allocation challenges by developing strategies to efficiently assign available parking spots to oncoming vehicles in a way that maximizes the overall utilization of the car park while ensuring a fair and user-friendly experience for drivers. Existing approaches to the car park space allocation problem have primarily focused on static optimization models or rule-based heuristics. While these methods have shown promise, they often lack the flexibility and adaptability required to handle the dynamic and stochastic nature of car park operations, where factors such as arrival patterns, parking durations, and user preferences can change rapidly over time.
This research problem seeks to address the limitations of current solutions by developing an intelligent and adaptive car park space allocation system that can learn from historical data and real-time observations to make informed, dynamic decisions on how to allocate parking spaces. The common thread across these studies is the recognition of the advantages that deep learning can bring to the car park space allocation problem. By leveraging the powerful pattern recognition and decision-making capabilities of deep neural networks, these approaches have demonstrated improved performance in terms of occupancy prediction, space allocation optimization, and adaptability to changing conditions, compared to traditional techniques [9]. Guruvareddiyur focuses on using a CNN Deep Learning model for Smart Parking to efficiently manage parking spaces by identifying empty and filled slots in parking layouts aiming to enhance parking experiences through smart utilization of space [10] .
As the field continues to evolve, further research is needed to address challenges such as incorporating user preferences, handling uncertain and incomplete data, and ensuring the scalability and robustness of deep learning-based car park management systems. Nevertheless, the existing literature provides a solid foundation for the continued exploration and development of deep learning solutions in this important transportation management domain.
A range of studies have explored the use of deep learning for car park space allocation [1] and [9] both used deep learning techniques to predict car park occupancy, with Camero focusing on car park occupancy rate prediction and Siddiqui on parking location prediction. Both studies demonstrated the accuracy and usefulness of their approaches. In their study, Sairam and his colleagues developed a system for automated vehicle parking slot detection using deep learning, achieving high recognition rates for empty parking slots [11] .Gopinath et al. further advanced this work by developing an automated parking lot space detection system using aerial imagery, which achieved high detection accuracy and real-time performance [12]. These studies collectively highlight the potential of deep learning for improving car park space allocation. Agrawal use convolutional neural networks (CNNs) to detect vacant parking spaces and utilize the PKLot dataset, an existing dataset, for the CNN-based approach.


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The *OpenCV* and *YOLO* model is better than the Traditional Methods in several ways. First, it is based on deep learning, which is a more advanced and powerful technique for computer vision tasks. This means that our model can learn from large amounts of data and improve its accuracy and performance over time.
Second, our model can detect different types of vehicles, including cars, trucks, and buses. Additionally, our model can detect objects at different scales and handle occlusions and overlapping objects.
Third, our model is more efficient and can perform real-time traffic counting, which is important for applications such as parking monitoring and surveillance. Overall, our *OpenCV* and *YOLO* model is a significant improvement over the traditional approach to traffic counting and offers better accuracy, efficiency, and flexibility. It can handle various scenarios, detect multiple types
This study aims to address the limitations of traditional allocation systems, which often rely on rule-based heuristics or static optimization models. While these approaches have shown promise, they lack the flexibility and adaptability required to handle the dynamic nature of parking operations, where factors such as user preferences and parking durations frequently change.

## Methods

This study employs a combination of *OpenCV* and a pretrained *YOLO* (You Only Look Once) model to detect vehicle parking occupancy. The methodology leverages the robust object detection capabilities of *YOLO* without additional training, allowing for real-time inference directly on the pretrained model. This approach is designed to simplify implementation while maintaining high accuracy in detecting occupied and vacant parking spots.

### *Proposed System*

In the proposed system, the collected dataset undergoes a comprehensive preprocessing procedure prior to initiating the vehicle detection phase. The raw data consists of surveillance video recordings captured from multiple angles around the NCB main building, as illustrated in Figure 1. These video feeds are initially processed using OpenCV, a widely used computer vision library, which performs essential image preprocessing tasks such as resizing to standard dimensions, cropping to focus on regions of interest, and frame extraction for real-time analysis.
After preprocessing, the system employs a *YOLO* to detect and locate vehicles within each video frame. The model analyzes each frame to identify vehicle positions and labels them accordingly.

***Figure*1 Photos of the obtained surveillance footage**

This detection process enables the system to identify occupied and unoccupied parking spaces, track vehicle movement patterns, and potentially integrate with a broader traffic or parking management system. Figure 2 illustrates the workflow of a smart parking occupancy detection system using computer vision and artificial intelligence techniques. It breaks down the process into four key stages, showing how surveillance footage is processed to determine parking availability.


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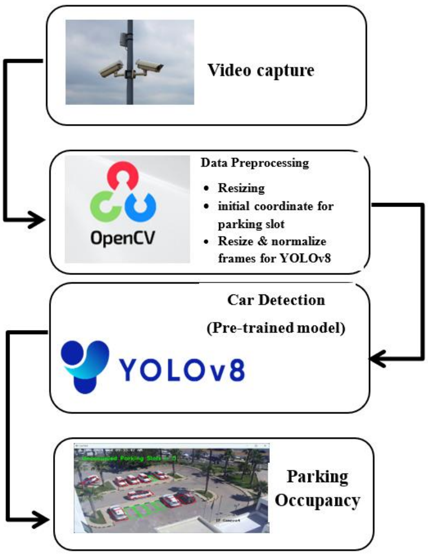


***Figure 2 system workflow***

Figure 3 presents a flowchart of a real-time system that reads video frames, detects cars, updates parking slot colors (green for available, red for occupied), adjusts the count of free spaces, and continues until no more frames remain. It effectively automates parking monitoring using object detection and simple decision logic.

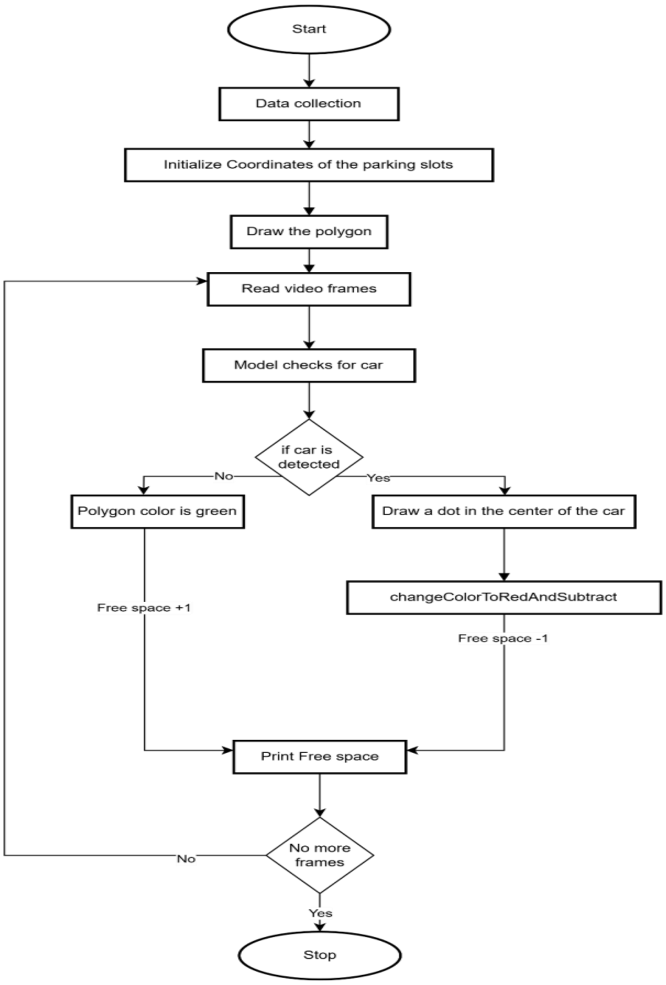


***Figure 3 Proposed system***

## Data Collection

We collected our data from many surveillance footage, as shown in Fig. 1 of the parking area of the NCB from 4 different angles. The more angles we have the more precise our system is, because usually 1 angle doesn't give a good view of certain areas, so we can avoid this obstacle with more than one point of view.


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### *Preprocessing Procedure Using OpenCV*

In the initial phase of the system development, a preprocessing step was conducted to prepare the parking lot dataset for further analysis. First, the coordinates of each parking slot were manually initialized by selecting the (x, y) points corresponding to the corners of each parking space within the video frames. This initialization step was performed once and served as a reference throughout the subsequent stages as shown in Fig 4.

After defining the parking slot coordinates, *OpenCV* was utilized to load the video frames captured from the parking area. For each frame, polygons representing individual parking slots were drawn using the predefined coordinates. Specifically, OpenCV's cv2.polylines() function was employed to overlay the boundaries of each parking slot on the frames, providing a clear visual segmentation of the parking areas. The annotated frames were displayed in real-time using cv2.imshow().


***Figure 4 Parking slot selection***

### *Detection Using pre-trained model (Yolov8)*

Following the preprocessing stage, which involved accurately labelling parking spaces on video frames, the detection stage was started. A YOLO model that had already been trained was used at this point to identify cars in real time. By cross-referencing the detected vehicle positions with the predefined parking slot coordinates, the system was able to accurately determine the occupancy status of each slot. YOLOv8, released in January 2023 by Ultralytics, offers five scaled versions: nano, small, medium, large, and extra-large. It supports object detection, segmentation, pose estimation, tracking, and classification. *YOLOv8* features an updated architecture with the C2f module for better feature extraction and an anchor-free model with a decoupled head, improving detection accuracy. It uses advanced loss functions like CIoU and DFL for bounding box loss, enhancing performance on small objects. The YOLOv8-Seg model achieves state-of-the-art results in segmentation tasks. With CLI and PIP support, *YOLOv8* is fast (280 FPS on NVIDIA A100) and achieves high accuracy (AP 53.9% on MS COCO) [13].

Rather than training the model from scratch, which requires large amounts of labelled data and computational resources, we use a pre-trained YOLO model for vehicle detection in parking lot images. The YOLO model has already been trained on a large, general-purpose dataset and can recognize various objects, including cars, in different contexts. The model is applied directly to the parking lot images without further fine-tuning or retraining. This approach leverages transfer learning, where the features learned by the pre-trained model are used for the specific task of detecting vehicle occupancy in parking spaces. By using this pre-trained model, we achieve high accuracy in parking space occupancy detection while minimizing the need for large labelled datasets and reducing the computational burden of retraining.

### *Model Evaluation Using Inference on Custom Data*

During inference, the YOLO model takes an input image and produces the object detection outputs (bounding boxes, objectness scores, and class probabilities) in a single pass. The model's outputs are then post-processed using non-maximum suppression (NMS) to remove overlapping or redundant bounding boxes and applying confidence thresholds to filter out low-confidence detections. In this study, the inference model was used to evaluate the accuracy of the model on custom data collected from National Commercial Bank's (NCB) main building. This unique dataset was used to test the pre-trained YOLO model's ability to recognize cars and distinguish between occupied and vacant parking spaces. Without requiring additional retraining, the inference results showed that the model could produce accurate and dependable outcomes in the specified context. The model's capacity to handle real-world data and achieve high parking space occupancy detection performance was validated by this evaluation, improving the system's dependability for real-world applications. Figure 5 shows the inference result.


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***Figure 5 model inference result on custom data***

YOLO Model Training: We are using the pre-trained *YOLOv8*, a state-of-the-art deep learning model for car detection without additional training for real-time car parking detection systems.

## Results

The YOLO model is used by our suggested approach to recognize cars in parking lot videos in real time. Technology can determine the number of vehicles in each region and determine the number of parking spaces that are available since detected vehicles are assigned to designated parking locations. This information is dynamically displayed on the video frame, providing a real-time view of parking availability.
The model's ability to accurately identify occupied and vacant parking spaces is seen in Fig 6. The detection results demonstrate the system's faultless ability to recognize cars and correctly assign them to parking spaces. This performance demonstrates the model's robustness and dependability in real parking lot environments.
These findings confirm the robustness and effectiveness of using a pre-trained YOLO model combined with OpenCV-based image processing for parking occupancy detection, outperforming traditional manual and sensor-based methods in both efficiency and accuracy.


***Figure 6 Detection Results in a 14-space parking***

## Discussion

The implementation of the parking occupancy detection system demonstrates a practical and efficient use of computer vision and deep learning techniques in real-world scenarios. By collecting surveillance footage from four different angles around the NCB parking area, the system overcomes the limitations of single-view detection, enhancing both coverage and accuracy. The preprocessing stage using *OpenCV* provide a strong foundation for accurate vehicle detection by allowing clear definition and visualization of each parking slot through manually initialized coordinates and polygon overlays.
The adoption of a pre-trained *YOLOv8* model for car detection proved to be highly effective. Rather than training a model from scratch—which would require extensive computational resources and labeled datasets—the use of transfer learning significantly reduced the development time and maintained high detection accuracy. The model's robust architecture and real-time processing capabilities enabled it to accurately detect vehicles and determine the occupancy status of each parking slot.


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Moreover, the system's inference on custom video data from the NCB environment confirmed the model's reliability and adaptability to new, real-world datasets without additional training. This demonstrates the scalability of the proposed approach and its suitability for broader deployment in smart parking systems. Overall, the implementation highlights the benefits of combining OpenCV-based image preprocessing with state-of-the-art deep learning models to create efficient, real-time vehicle detection solutions.

## Conclusion

In this study, the *YOLOv8* model—an advanced deep learning architecture known for its high precision and real-time object detection capabilities—was employed to develop an effective vehicle parking occupancy detection system. By leveraging the pre-trained version of *YOLOv8*, the deployment process was significantly simplified, enabling seamless integration into the proposed framework without the need for additional training or fine-tuning. The model was embedded within a real-time detection system designed to process video footage from a parking facility at the NCB main building. For each frame, *YOLOv8* efficiently identified vehicles by generating bounding boxes and accurately determining their positions within the scene. The experimental results demonstrate that the pre-trained *YOLOv8* model delivers robust and accurate performance in detecting vehicles in real-time, even without domain-specific retraining. This highlights the model's capacity to generalize effectively across different environments and datasets, making it a practical solution for parking space monitoring applications. Overall, the findings of this study underscore the transformative potential of state-of-the-art deep learning models such as *YOLOv8* in enhancing urban mobility and resource management. The successful implementation supports the advancement of intelligent transportation systems and paves the way for more efficient, data-driven urban infrastructure solutions.

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