

# A REAL-TIME VISION-BASED PARKING SLOT OCCUPANCY DETECTION USING YOLOV8 UNDER VARYING ILLUMINATION CONDITIONS

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**Abstract:** Due to rapid urbanization efficient parking management has become a critical challenge for cities leading to parking congestions and adverse impact of it on environment. Computer vision-based parking system is a scalable and cost-effective solution to manage smart cities. This paper presents a real time, computer vision based YOLOv8 Object Detection model for intelligent parking system which is designed to operate robustly under different environment and lighting conditions. The proposed model was initially trained and validated using YOLOv8 on publicly available PK\_Lot data subset containing 6998 annotated images under different weather conditions. To enhance real world applicability, the evaluation was conducted on continuous CCTV video captured from different parking environment. Manually annotated frames are extracted from real world CCTV video to address multiple real world parking challenges such as motion blur, elimination glare, different camera angles, partial occlusions and improper parking layout. As the results on real world data set are not satisfactory so the combined data set with PK\_Lot and annotated frames from real CCTV recordings included for enhanced generalization capabilities. A total of 8798 annotated frames are extracted and 879 frames are used for structural testing. The experimental results obtained from enhanced dataset gives high detection accuracy of 99.49%, precision of 99.69%, recall of 99.47% and F1 score of 99.58% demonstrating reliable performance under different practical deployment conditions. The result confirmed the robustness of the proposed framework against real -world conditions, making proposed system suitable for scalable intelligent parking management system for smart city..

**Keywords:** Vision-based Parking System, YOLOv8, Parking Slot Occupancy Detection, Intelligent Transportation System, Smart City, Computer Vision.

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## 1. INTRODUCTION

A significant rise in private vehicle ownership in the cities has intensified parking congestion in metropolitan areas. These demands a good infrastructure like roads and parking system. A shortage in parking spaces especially during peak hours and large public events put pressure on city administration. This also leads to the traffic congestion, fuel consumption and environment pollution. [1] [2]. Research shows, intelligent parking systems involving sensor network and/or computer vision-based algorithm provide efficient management of parking system.

Initial research in this field were based on sensors embedded into parking slots and wireless networks were used for communication. They give real time parking occupancy information through mobile phone connectivity [3].

However large-scale deployment was a challenge due to both installation and maintenance cost [4]. This restricted large scale implementation and were vulnerable to environmental inferences. Off late computer vision-based systems with deep learning algorithms have gained attention. Using an existing surveillance infrastructure like Close Circuit Tele Vision (CCTV) cameras, vision-based algorithms offer scalable and cost-effective solutions to sensor-based methods [5] [6]

However, most of these studies offer evaluations under static or controlled conditions and therefore fail to maintain performance under uncontrolled conditions [7] [25]. Therefore, it is critical requirement for intelligent parking systems that consider challenges such as motion blur, camera vibrations or different lightening conditions.

The present study considers addressing some of these conditions. It is a real time parking slot detection system using You Only Look Once (YOLO)v8 framework and integrates slot detection, occupancy, identification and vehicle detection under various light conditions. PK\_Lot dataset was used for training and validation. Testing is done on real-world CCTV footage captured across diverse condition like day light, afternoon glair and nighttime scenarios. Performance metrics were evaluation for each light condition and over a complete video sequence. The result obtained have demonstrated high accuracy and reliability across varying lightening conditions. This makes the system robust and suitable for considerations as an intelligent parking system under smart city environments.

The details of the paper are organized as related literature is reviewed in section 2. Section 3 presented the methodology followed by results in section 4, in section 5 typical conclusion are presented.

## 2. RELATED LITERATURE

Due to rapid urbanization and challenges related to the parking infrastructure, development of intelligent parking management system is the need of hour. Early solutions used sensor-based technologies to detect parking occupancy accurately, but the adoption of it is limited with multiple challenges in terms of cost, maintenance and scalability issues. The adoption of deep learning models and multi-layer inference frameworks, has further improved detection accuracy, robustness but limited to different environment conditions. Several studies have demonstrated the effectiveness of advanced object detection model in parking and transportation related applications. YOLOv2 and ResNet based framework for license plate recognition achieving high detection and classification accuracy across multinational datasets [10]. Region-based convolutional neural network (R-CNNs) and transformer-based architect such as DETR have also shown strong performance in object detection task [11-12] Among these approaches, single stage detectors – particularly the YOLO family have gained widespread adoption due to real time inference capability and suitability of time critical applications [13]. Improved versions such as YOLOv4 and YOLOv5 have further enhanced detection accuracy and computational efficiency, making them suitable for intelligent parking system [14-15].

To reduce computational requirement and enable deployment on edge devices, light weight models such as Tiny-YOLO(T-YOLO) and MobileNet have been explored. These methods presented better accuracy, speed and other resource optimization. However, deep learning methods remained highly compute intense and required hardware and energy resources. [16-19]

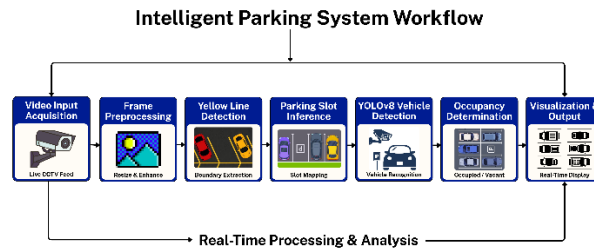
IOT and Narrowband IOT(NB-IOT) methods were also utilized for parking systems. Some of these methods presented real time communication and centralized controls. These systems were susceptible to signal interference and needed continuous maintenance. [21-23]. Lack of standard datasets have poses challenges. [24]. This critical examination of literature offers potential of using computer vision-based techniques for parking management systems. However very scarce literature is available on real world challenges in developing a scalable and robust parking system. These inputs have motivated the present study to consider robust, efficient and intelligent parking system for smart cities.

## 3. METHODOLOGY

The aim of the research is to present a robust and real time intelligent parking system. The system focused on the capabilities of accurately determining the parking slots and their occupancy status under diverse lighting and motion conditions.

The present method makes use of YOLOv8 for vehicle detection, occupancy identification and visualization. A PK\_LOT parking data set was used for training, validation and testing in the ratio of 70,20 and 10 percent. The trained system is interconnected with images captured from real world CCTV footages on a common platform as shown in Fig.1. Frame preprocessing, yellow line detection and parking lot inference were conducted on the live stream sequentially. This is then followed by vehicle detection and visualization based on the trained model on YOLOv8.

The model was trained for day and night lights, afternoon glares and image blur conditions. Different light conditions considered for the study are shown in Fig. .2



**Fig. 1: Intelligent parking System Workflow**



**Fig. 2: Visuals of Parking under different lighting conditions**

Dataset:

The proposed intelligent parking management system used was trained and evaluated using combination of a publicly available dataset and real-world surveillance data. Training and Validation on PK\_Lot dataset was used, which contains annotated images of occupied and vacant parking spaces captured under different lighting conditions including sunny and cloudy. The dataset provides various viewpoints, illumination and vehicle appearance making it suitable for training deep learning based parking occupancy detection models.

For real world applications, the trained model was further tested on continuous video captured from a fixed overhead CCTV camera. The video includes real world challenges representing static dataset for motion blur, sudden light effects, illumination glare, partial occlusions. The combined dataset helps us for the evaluation of both detection accuracies on standard benchmark and robustness in real-world scenarios.



**Fig. 3. Parking slot occupancy under different lighting conditions**

Dataset Preparation, Real-World Applicability and Enhancement in PK\_Lot Dataset:

The PK\_Lot dataset was used for training, validation and initial testing of proposed parking model which consists of 6998 annotated images for occupied and vacant parking slots under different conditions like sunny, cloudy

and rainy. The systematic evaluation was conducted on the dataset into 70% training (4878 images), 20% validations (1399 images) and testing was performed on 10% (701 images). This helps for unbiased performance model.

To assess applicability in real world situation and for robustness, the trained model was evaluated using continuous CCTV video under different parking scenarios. The parking scenarios were with real world challenges such as illumination glare, partial occlusion, motion blur, different camera angles, in proper parking layouts.

To enhance the performance of model the proposed study gives enhancement of PK\_Lot dataset with manually annotated frames extracted from real world CCTV videos from diverse parking scenarios. These scenarios are underground parking, open outdoor parking, unstructured Indian parking layouts.

The enhanced PK\_Lot dataset with the integration of images from multiple camera angles and different lighting conditions were used. A total of 8798 annotated frames were extracted at one frame per second (FPS) from continuous video footage. Out of which 879 frames corresponding to nearly 14.60 minutes of video duration were used for testing.

This combined dataset approach with benchmarking PK\_Lot images and manual annotated real world CCTV videos supports real world applicability and robust performance for training, validation and testing under different lighting conditions. The prior studies [29] have demonstrated parking slot boundary detection using HSV color threshold, edge detection and Hough Line Transform techniques were used for detection of Yellow Line geometries. The proposed study gives the extension for boundary detection, parking slot detection by integrating occupancy classification and applicability in real world scenarios as shown in Fig. 3.

**System Requirements:**

The system requirements are as 32 GB RAM, 8 GB GPU, NVidia RTX 4060, Windows 11, Intel i7 Processor 16 cores. The technology used is Python and Images annotated using Roboflow. The dataset enhancement (fine-tuning) and annotation process was carried out using Roboflow for real world CCTV video, which provides an efficient platform for image annotation dataset, management and pre-processing. Roboflow was utilized to organize audited images, perform data set versions, and also used for preprocessing in the form of resizing and normalization. The Roboflow platform also facilitated the seamless data set, splitting into training, validation and testing, subset, ensuring reproducibility and data integrity. The use of Roboflow streamline the data pipeline and contributed to reliable and consistent model training and evaluation.

**Vehicle detection using YOLOv8:**

Vehicle detection is performed by using YOLOv8 which is object detection model, it offers high accuracy and it is real time inference suitable for intelligent parking system. YOLOv8 detects vehicles in each video frame and assigns a confidence score to every detection. This detection helps for true vehicle detection.

**Occupancy determination using Geometric Analysis:**

To determine whether a parking spot is occupied, two complementary metrics are employed: center distance and Intersection over Union (IoU).

**Geometric Centre Calculation:** For each inferred parking spot rectangle, the geometric center is calculated using Eq.1 and 2:

$$\text{Center}(x, y) = \left( \frac{x_1+x_3}{2}, \frac{y_1+y_3}{2} \right) \text{----- (1)[29]}$$

where  $x_1, y_1, \text{ and } x_3, y_3$  are opposite coordinates of the rectangle.

$$\text{Center}(x, y) = \left( \frac{x_1+x_2}{2}, \frac{y_1+y_2}{2} \right) \text{----- (2)[29]}$$

where  $x_1, x_2, \text{ and } y_1, y_2$  are the top-left and bottom-right coordinates of the bounding box.

**Distance Measurement:** The Euclidean distance between the parking spot center and the car center were calculated using Eq.3

$$\text{Distance} = \sqrt{(x_{car} - x_{spot})^2 + (y_{car} - y_{spot})^2} \text{----- (3) [29]}$$

**Threshold-Based Classification:** If the distance is within a threshold (e.g., 10-20% of the parking spot's width), the spot is classified as occupied.

**Priority Assignment:** If multiple cars overlap a single parking spot, the system selects the car whose center is closest to the parking spot center.

**Enhanced Visualization:**

Visual Debugging: Lines connecting parking spot centers and car centers are drawn for debugging purposes.

Dynamic Color Coding: The color of parking spots is updated in real-time to reflect their status.

This is shown in Fig.3

IoU measures the overlap between the detected car's bounding box and the parking spot's defined area. It is more robust than a simple overlap percentage because it penalizes for areas that don't align. It is calculated as the ratio of the area of the intersection to the area of the union of the two shapes as in Eq.4.

$$IoU = \frac{Area(Spot \cap Car)}{Area(Spot \cup Car)} = \frac{Area_{Intersection}}{Area_{Spot} + Area_{Car} - Area_{Intersection}} \quad \text{----- (4)}$$

Percentage available spots was determined using Eq.5.

$$Occupancy\ Ratio(\%) = \left( \frac{Total\ Occupied\ Spots}{Total\ Number\ of\ Parking\ Spots} \right) \times 100 \quad \text{-----(5)}$$

**Real-Time Visualization:**

A color code visualization was used for indication as Red for occupied, green for vacant.

**Performance Evaluation Metrics:**

System performance is evaluated using standard classification metrics as in Equation 6 to 9.:

Accuracy:

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \quad \text{----- (6)}$$

Precision:

$$Precision = \frac{TP}{TP+FP} \quad \text{----- (7)}$$

Recall:

$$Recall = \frac{TP}{TP+FN} \quad \text{----- (8)}$$

F1-Score:

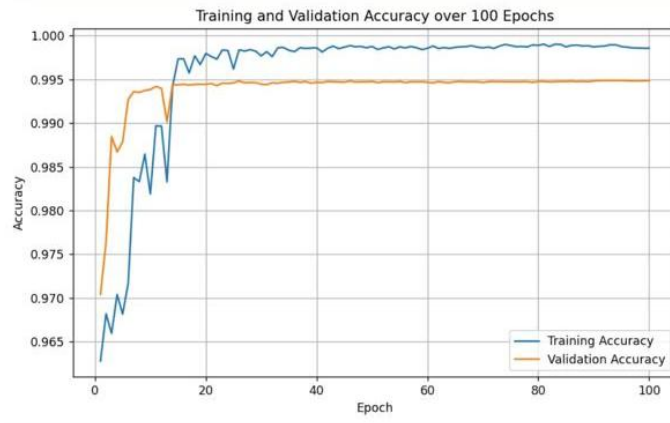
$$F1 = 2 \times \frac{Precision \times Recall}{Precision+Recall} \quad \text{-----(9)}$$

Where TP denotes true positives, TN denotes true negatives, FP denotes false positives and FN denotes false negatives.

## 4. Results

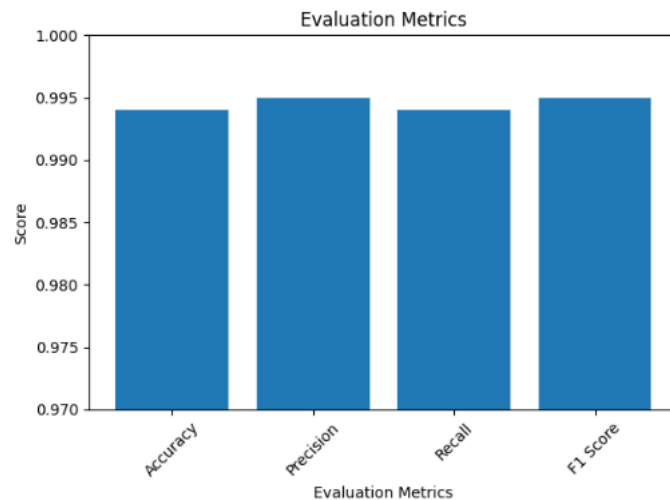
The proposed vision-based intelligent parking system was evaluated to assess its effectiveness in terms of accuracy detection of parking slot identification in real world conditions. The evaluation focuses on detection in different lighting conditions in terms of accuracy, robustness, real world challenges for daylight, afternoon glare, illuminations, occlusions.

A. Baseline Performance on PK\_Lot Dataset: The PK\_Lot dataset contains static images and the dataset is from Brazil and it contains images in Sunny, Cloudy and Rainy weather conditions. The YOLOv8 model was trained and evaluated on 100 epochs initially on PK\_Lot dataset. The model achieved accuracy of 99.49%, Precision of 99.69%, Recall of 99.47% and F1-score of 99.58%. As shown in Fig. 4, The model achieved high accuracy, demonstrating its capability for identifying parking lots accurately under different lighting conditions. These results confirm that the model performs effectively on PK\_Lot dataset.



**Fig. 4: Training and Validation performance of YOLOv8 on PK\_Lot dataset**

This shows that the model converges smoothly on PK\_Lot dataset showing stable behavior. This proves that the model is trained well.



**Fig. 5: Baseline performance metrics of YOLOv8 trained and evaluated on PK\_Lot dataset**

Figure 5, proves that the model is trained well and shows high performance metrics.

Testing on Real-World CCTV videos: CCTV videos under different lighting conditions were collected from Indian Parking scenarios and testing was performed on YOLOv8 to check Real World applicability. But, as shown in Fig. 6, it has been observed that there is significant drop in the detection performance. This reduction indicates that due to unseen domain conditions the results are not as expected. It shows the shift requirement of variation in camera viewpoints in terms of angles, illumination changes, occlusions and no standard parking layouts.

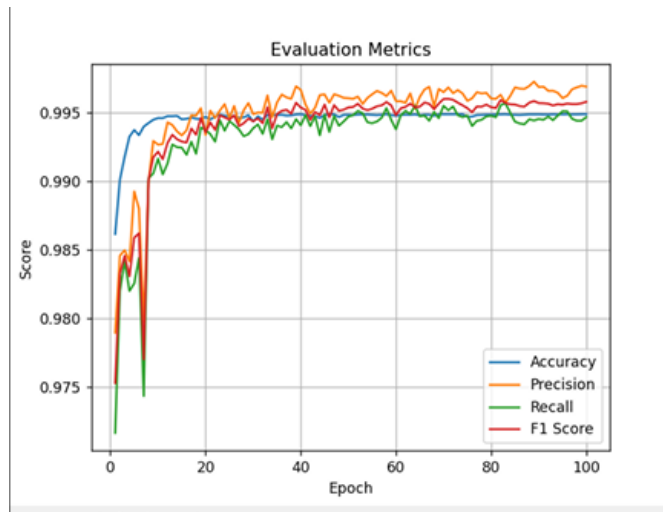


**Fig. 6 a) Video- Daylight testing results**

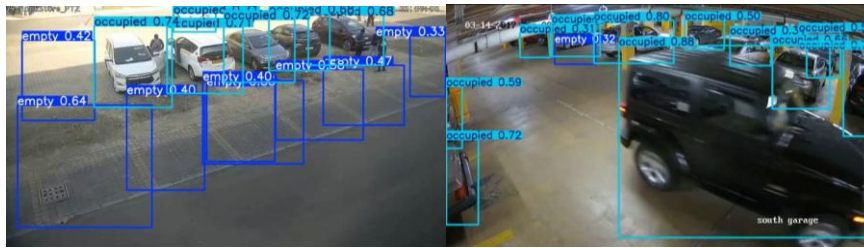
**Fig. 6 b) Video- Night and low light conditions**

**Fig. 6: Drop in testing of different CCTV Video-Detection failures under different lighting conditions**

Evaluation Enhanced PK\_Lot dataset: The enhanced PK\_Lot dataset was enriched with the annotated images from various real-world scenarios forming a combined dataset. The YOLOv8 model was retrained using this enhanced dataset and the improved performance is observed in terms of accuracy which is reported as 99.49%, Precision of 99.69%, recall of 99.47% and F1 score of 98.0% as shown in Fig. 7.



**Fig. 7: Training & Validation -Performance Metrics of proposed intelligent parking system on Enhanced PK\_lot dataset**



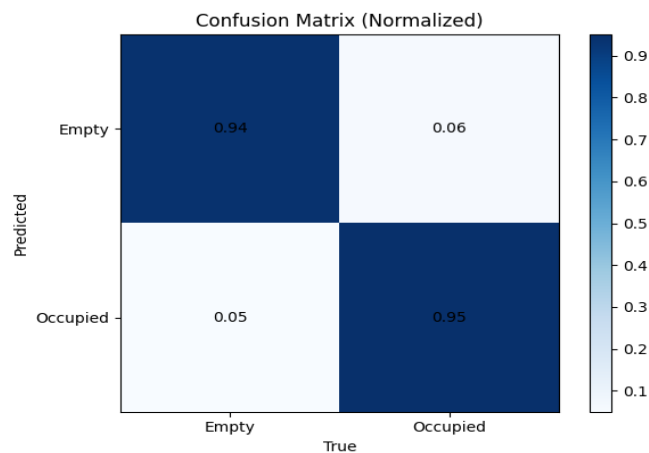
**Fig. 8a) Detection After Enhancement-Daylight Fig. 8b): Detection After Enhancement-Nightlight**  
**Fig. 8: Testing Results of Detection After enhancement on PK\_Lot Dataset**

Figure 8, shows with enhancement in PK\_Lot dataset there has been great improvement seen in the detection accuracy and improving all performance metrics under different parking conditions. Table 1 gives the comparative performance on PK\_Lot dataset, Real-World testing video and Enhanced PK\_Lot dataset where the performance drop is observed in testing of Real-World testing video leading to the enhancement and integration of datasets.

**Table 1: Comparative Results-Performance Improvement**

Dataset	Training Data	Testing Data	Accuracy	Precision	Recall	F1-score
PK_Lot	PK_Lot	PK_Lot	99.48%	99.86%	99.89%	99.87%
Real World testing CCTV video	PK_Lot	CCTV Video	82.36%	78.41%	74.90%	76.61%
Enhanced PK_Lot	Enhanced PK_Lot	CCTV Video	99.49%	99.69%	99.47%	99.58%

The above comparative analysis demonstrates that the enhancement in the PK\_Lot dataset plays important role in the real-world applicability of intelligent parking system considering different real-world parking challenges. Figure 9 shows that the Confusion Matrix of YOLOv8 model trained on Enhanced PK\_Lot dataset and tested on CCTV video.



**Fig. 9 Confusion Matrix of YOLOv8 model trained on Enhanced PK\_Lot dataset and tested on CCTV video.**

Comparison with Existing Methods:

As shown in the Table 2 below shows that the proposed system achieves higher accuracy compared to existing sensor based and vision-based approaches while maintaining real-time performance. Unlike several other researches and studies for different lighting conditions, the proposed system explicitly analyses performance across daylight, afternoon glare and night-time scenarios using real-world CCTV footage. Table 5 summarized and shows the proposed YOLOv8 based framework with automatic slot inference demonstrates consistency high accuracy across varying lighting conditions highlighting its robustness and suitability for real world smart parking deployment.

**Table 2. Comparison of the Proposed Parking System with existing parking Occupancy Detection Methods under different lighting conditions**

Study	Approach	Dataset/ Environment	Lighting conditions evaluated	Metrics Reported	Accuracy (%)	Key Limitations
Huang & Vu [24]	Multilayer Inference	Real Parking Scenes	Daylight, Shadows	Accuracy, Precision, Recall	95 %	Sensitive to heavy shadows
Farley et al. [25]	Classical CV	Controlled Parking, Images from camera	Day, Low light	Accuracy	93.15%	Strong illumination sensitivity
Nyambal & Klein et al.[26]	CNN-based	PKLot	Sunny, Cloudy	Accuracy	Upto 99%	Manual Slot detection
Amato et al. [27]	CNN-based decentralized System	Real World Parking lots	Variable illumination, occlusions	Accuracy	96%	Requires decentralization processing infrastructure
Encio et al. [28]	Context Aware	Multiple Parking	Daylight, Glare, low light	Accuracy, Recall	98%	Higher Computational complexity
<b>Proposed methodology</b>	<b>YOLOv8 + Automatic Slot Inference</b>	<b>PKLot+ Real CCTV</b>	<b>Daylight, glare, low light</b>	<b>Accuracy, Precision, Recall, F1</b>	<b>99.48 % (PKLot) , 99.49 % (CCTV)</b>	<b>Robust across illumination, no manual slot labelling</b>

The result demonstrated that the proposed framework performs with reliable output on CCTV video. The proposed study validates the system using continuous surveillance footage that reflects better real-life scenarios.

## 5. CONCLUSION

The study proposed a robust vision based intelligent parking system which is capable of effective detection of parking slots under different lighting conditions and real-world scenarios. With the benchmarking of PK\_Lot dataset for training and validations the model achieved reliable performance. With the incorporation of manually annotated CCTV frames representing different parking scenario has significantly improved the system applicability to real world parking scenarios. The enhance dataset which is with the integration of PK\_Lot and CCTV images gives systematic evaluation under real world challenges such as motion blur, glare, different camera angles and improper parking layouts. The validations confirmed that with the integration of benchmark data and real world annotated frames the performance is improved in term of accuracy and robustness.

Overall the proposed approach bridges the gap between the static dataset performance and practical real-time implementation. the system demonstrated string potential in the implementation of intelligent parking systems in smart city infrastructure and transportation framework.

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