Proceedings of the International Conference on Modern Sustainable Systems (CMSS-2025)
DVD Part Number: CFP250Q9-DVD; ISBN: 979-8-3315-6509-1

YOLOv5-based Parking Space Detection for Reducing Urban Congestion and Fuel Wastage

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***Abstract*—Urban congestion and fuel inefficiency are significant challenges in contemporary cities, often aggravated by suboptimal parking space management. This research introduces a high-efficiency YOLOv5-based system for parking spot identification aimed at delivering real-time availability notifications, decreasing search duration, and reducing fuel usage. The solution combines IoT-enabled cameras with YOLOv5, using its advanced object recognition skills to precisely identify unoccupied and occupied parking spots. Comprehensive testing was performed on parking images from various metropolitan settings under differing lighting and meteorological conditions. The proposed system achieved accuracy of 99.31%, markedly exceeding traditional image processing techniques and other deep learning (DL) models. Real-time detection technology decreased the average parking search duration and reduction in fuel consumption per car each trip. Moreover, the model exhibited an inference speed of 9 ms per frame, facilitating smooth real-world implementation. These findings highlight the potential of YOLOv5 to revolutionize smart city parking systems, alleviate traffic congestion, and enhance environmental sustainability. Future research will focus on enhancing computational efficiency for extensive urban applications and using predictive analytics for adaptive parking management.**

Keywords—Parking Space Detection, Smart Parking, Real-Time Object Detection, Smart City Solutions, Computer Vision

I. Introduction

Urban congestion is an escalating issue in contemporary cities, exacerbated by the ineffective pursuit of parking places. Motorists spend considerable time and fuel searching for available parking spaces, exacerbating traffic congestion, air pollution, and fuel depletion. Smart parking solutions using modern technology have garnered considerable interest in solving this problem. Parking space detection systems use IoT sensors, computer vision, and machine learning to monitor and locate available parking spaces in real-time. These technologies provide drivers with immediate updates via mobile apps or digital displays, minimizing the time allocated to locating parking.

Optimizing parking space use reduces traffic congestion and minimizes wasteful fuel consumption and emissions, promoting sustainable urban mobility. Cloud computing facilitates fast data processing and storage, enabling cities to examine parking trends and enhance infrastructure design. Additionally, AI-driven prediction algorithms improve the forecasting of parking spot availability, hence optimizing urban traffic management. With the continuous growth of urban populations, implementing intelligent parking systems is essential for improving transportation efficiency. Parking spot detection systems enhance urban living quality by alleviating congestion and minimizing fuel use, fostering cleaner, more intelligent, and sustainable cities.

II. Literature Survey

To enhance the precision of ultrasonic sensors, this work presents a parking space recognition method that uses the Streaming Data Evolution Clustering Method (SDECM) [1]. The technique employs a semi-supervised autoencoder with the Extreme Learning Machine (ELM) to extract local structural characteristics. The approach outperforms state-of-the-art approaches in boundary point recognition across various space and vehicle speed scenarios, precisely localizing space boundaries. This study presents a new method for detecting vehicle parking slots using YOLOv8, a state-of-the-art object identification algorithm [2]. This research aims to optimize parking space utilization and fulfill the growing need for effective parking management in metropolitan settings to ease traffic congestion.

The study suggests a novel approach to automating the discovery of parking spaces in metropolitan settings using computer vision technologies [3]. It employs OpenCV for image segmentation, DL models for object identification, and region-specific masking. Offering a strong and automated solution for parking management, this technology improves accuracy and scalability. By using state-of-the-art computer vision methods, this study aids in creating and implementing smart parking systems [4]. Specifically for low-computation devices, the research trains a Custom Object Detection model using a subset of the Google Open Images Dataset that focuses on parking spots. The feature pyramid network (FPN) and the YOLOv5 architecture allow the system to identify parking spots and items inside them accurately.

Developed and emerging countries face the same major problem: parking congestion in their metropolitan regions [5]. It suggests using the YOLOv8 algorithm to find empty parking spots. Working on software that will let parking lot managers and drivers find available spots easily [6]. Each parking spot's condition may be ascertained using an AI-driven application logic that integrates real-time image analysis with the parking lot's virtual model.

This work proposes a pixel-based image processing method for real-time parking spot recognition [7]. The proposed algorithm finds open spots in a live video feed of a congested parking lot. After running the algorithm through its paces, it is compared against a CNN algorithm using the YOLOv8 software. The need to expand parking management systems has been driven by the rise in car usage, which is a direct result of urbanization and population growth [8]. It presents a novel approach to managing available parking spots in monitored garages using DL. With keyframe detection, this approach employs the Dragon Lake Parking dataset to cut down on memory and compute expenses caused by excessive learning and repeated frames.

It introduces a vacancy detection system that was trained using data collected from the parking lot of the University of Zilina during the winter months of December through January. With its solid real-time performance, this instrument is a boon to intelligent parking systems and provides effective outdoor parking management all year round. It presents a technique for automatically detecting when parking slots are full [10]. A new approach is proposed that is based on image processing methods that are developed from computer vision. Using a combination of web browser and mobile app access, the system provides convenient real-time monitoring of parking lots via real-time camera video footage.

It presents an algorithm that can recognize parking spaces and identify their states using past and present video footage captured by parking cameras [11]. Space utilization and administration expenses are both enhanced by the concept. Using input data on parking spaces, it also suggests a method for short-term demand prediction for on-road parking using CNNs and LSTMs. It provides an image processing method for detecting available parking spots [12]. The technology finds empty parking lot spots and uses image processing to determine available ones. These strategies might be integrated into mobile apps to further assist drivers in finding parking places, enhancing their whole experience.

Incorporates a camera based on the Raspberry Pi model for precise vehicle identification and is driven by the innovative Internet of Things (IoT) intelligent parking system [13]. Message Queuing Telemetry Transport (MQTT) is a communication protocol that transfers machine-to-machine (M2M) data from the Raspberry Pi to a server over a wireless sensor network. DL methods were used to train the model. An intelligent parking system based on a tripod method and employing commercially available components is shown in the study [14]. Administration via the cloud, control of parking spaces, and user administration are all part of the system. Whether coupled with an Arduino UNO microcontroller, infrared sensors can identify whether a room is occupied. Data is sent using the Wi-Fi protocol, and Blynk is used to access cloud services. It provides the model for the efficient administration of medium-sized parking lots.

Using inexpensive IoT infrastructure, this article proposes a smart parking control system [15] that gathers parking status data from sensors distributed to various spots and processes it automatically and in real time. Powered automatically by solar panels, the parking status is reported to Amazon Web Services' IoT platform. Population increase, increased urbanization, inadequate infrastructure, and social and economic shifts contribute to the world's worst traffic problem: gridlock [16]. Using real-time aerial data, a novel video-based parking strategy manages parking places. The system employs state-of-the-art image processing and computer vision for occupancy position detection. It found that out of 41 spots, 7 were empty. The system employs Gaussian blur filtering, binary threshold, and a median filter to enhance detection accuracy and identify the Region of Interest.

Train a parking lot's unoccupied space detection network, which presents a task-consistency learning approach. It lessens the impact of distracting incentives and utilizes a symmetric constraint to identify tainted samples [17]. The approach is adaptable, so it's simple to implement and update without requiring a lot of manual labor. Compared to traditional supervised detection approaches, experimental results demonstrate that the noisy task consistency process can train an unoccupied space detector from the ground up. The physical features of parking lots that need turning around and rerouting on public roadways are combined into two patterns, and aerial images are used to recognize each pattern semi-automatically. The parking limits and the orientation of parked cars are factors that contribute to discrimination. For vehicle detection, YOLOv5 is used, and for boundary line identification, template matching of the lines' endpoints is used.

Urban parking management is more important than ever due to rising vehicle populations and insufficient parking facilities. This research aims to evaluate several machine learning (ML) models for predicting the availability of parking spots in intelligent systems that the IoT enables. A parking identification approach with a magnetic wireless sensor network has been proposed [20]. This algorithm uses the translation-invariant wavelet denoising technique to preprocess the magnetic signals, to mitigate noise, and to reach the detection standards. A multi-transitory finite state machine was developed for parking identification using variance signals, considering the issues of weak magnetic cars and interference from nearby vehicles in real-world applications. YOLOv5 improves traditional YOLO iterations by offering accelerated inference, reduced model size, improved accuracy, automated bounding box learning, and superior data augmentation, provide it optimal for real-time applications such as parking detection. A comparison and analysis of the literature review is shown in Table 1.

TABLE I. LITERATURE SUMMARY

Ref No	Objective	Proposed Method	Results

[21]	A technique for automatically allocating parking spots in cities, which should make parking management much more efficient.	The novel automated vehicle parking system that has been proposed is an attempt to solve typical problems with conventional parking systems by providing a more structured and mechanised alternative.	Several examples show that the approach greatly improves operational efficiency and user happiness in real-time applications.
[22]	An IoT smart parking system can utilise computer vision to find open spots in real time, which is a huge help for dealing with parking problems in densely populated areas.	Cameras monitor parking spaces to provide accurate occupancy statistics and assist users identify available places easily.	An Android software provides users real-time parking information, saving them time.
[23]	This study examines the development and assessment of an automated parking system to improve urban parking facility availability and protection.	It uses real-time sensor data to indicate parking availability and lets customers reserve spots via a secure mobile web app.	Drivers can easily find their scheduled places using the app. OTP protects parking against unauthorised use.
[24]	A new parking space management and unauthorised parking solution using machine learning and motion detection.	The technique uses powerful machine learning models such RCNN for object identification and YOLOv8 for license plate recognition.	The system's automatic vehicle recognition, real-time monitoring, and notification alerts strengthen resident and visitor car verification.

III. PROPOSED SYSTEM

The proposed YOLOv5-based parking space detection system aims to enhance urban parking management by delivering real-time information on available parking spots. The system incorporates IoT-enabled cameras, DL algorithms, and cloud computing to enhance detection precision, decrease search duration, and mitigate fuel use. The technology utilizes computer vision and artificial intelligence to accurately classify parking spots as empty or occupied, enabling smart city solutions for traffic and congestion management.

A. Data Acquisition and Preprocessing

The technology initiates data collecting with IoT-enabled cameras strategically positioned in parking facilities. These cameras incessantly document photographs of parking spots under diverse settings, including varying illumination, meteorological fluctuations, and impediments. To provide model reliability, the PKLot dataset, a publicly accessible resource for parking space recognition, is used with dataset gathered from several urban parking sites. This amalgamation augments the model's capacity to generalize across many contexts.

Preprocessing methods enhance image quality and annotation precision. Images are subjected to noise reduction, contrast enhancement, and segmentation to effectively emphasise parking spots. Data augmentation techniques, including flipping, rotation, and brightness modification, replicate real-world fluctuations, assuring the model responds well to diverse settings. Each image is annotated to denote the occupancy status of a parking spot, creating a systematic dataset for model training.

B. YOLOv5-Based Parking Space Detection

The detection phase uses the YOLOv5 DL model, optimized for real-time object identification. The program analyses input images from IoT cameras to identify parking spaces using bounding box regression and classification. YOLOv5 is selected for its rapid inference speed, superior accuracy, and lightweight design, making it appropriate for practical implementation in smart parking systems. The model is trained with the PKLot datasets, ensuring flexibility in diverse parking settings. Critical hyperparameters, including batch size, learning rate, and IoU threshold, are optimized to enhance detection accuracy. The YOLOv5 network adeptly differentiates between occupied and unoccupied spots, enabling prompt and dependable updates on parking availability.

C. Cloud-Based Processing and Data Transmission

Upon detection and classification of parking spots, the data is communicated to a cloud-based server for further processing and storage. Cloud computing facilitates the management of substantial data quantities, making it scalable for monitoring several parking sites simultaneously. The cloud platform manages users' storage, analysis, and dissemination of real-time parking availability updates. The system utilizes MQTT and HTTP protocols for effective data transfer across IoT cameras, cloud servers, and end-user apps. Cloud-based analytics provide insights into parking trends, occupancy patterns, and peak use periods, facilitating informed decision-making for urban traffic management. The cloud architecture facilitates smooth interaction with navigation systems and mobile apps.

Figure 1 illustrates the process of the YOLOv5-based parking space detection system using a block diagram. IoT cameras record parking images subjected to preprocessing and dataset integration. The YOLOv5 model identifies unoccupied and occupied areas, relaying information to a cloud server. Users get real-time parking information via a mobile application and online dashboard.

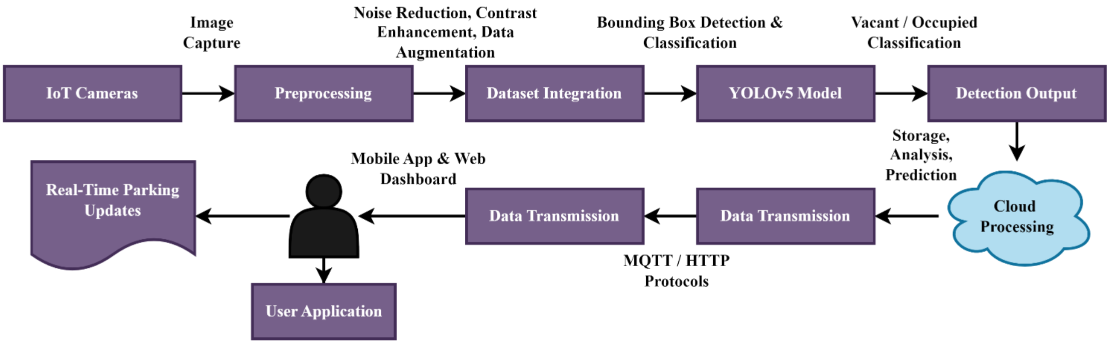

Fig. 1. Proposed Flow of YOLOv5-Based Parking Space Detection System

D. Real-Time Parking Availability Updates

The concluding step entails the real-time distribution of parking availability information via a mobile application and online dashboard. Users may get real-time information on available and occupied parking spaces, enabling them to strategize their parking in preparation. The technology offers GPS navigation, guiding cars to the next available parking space, alleviating congestion from superfluous vehicle movement. The mobile application provides supplementary features such predictive analytics for forthcoming parking patterns, automatic notifications for spot availability, and interaction with digital payment methods. The technology minimizes the duration of parking searches, saving fuel consumption, alleviating traffic congestion, and enhancing urban mobility.

Figure 2 illustrates the architecture of YOLOv5. The YOLOv5 model has three primary parts: the Backbone, which uses convolutional and CSP layers to extract image feature; the Neck, which integrates data across various scales using FPN and PAN for enhanced localisation; and the Head, which forecasts bounding bounds and classifies objects. This stratified design enables real-time, precise identification of occupied and unoccupied parking spots, crucial for alleviating congestion and enhancing parking efficiency in urban environments.

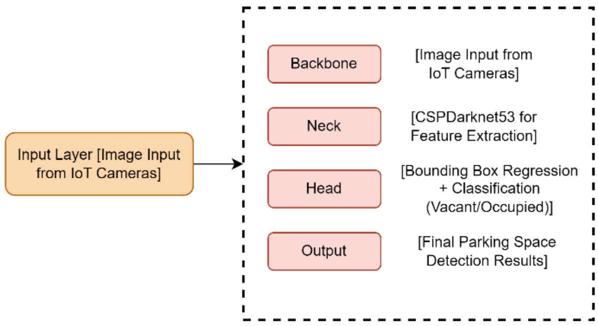

Fig. 2. YOLOv5 Architecture for Parking Space Detection

E. Bounding Box Prediction Equation

YOLOv5 uses the following transformation equation 1, 2 to forecast bounding boxes:

$$\hat{x} = \sigma(t_x) + c_x, \qquad \hat{y} = \sigma(t_y) \quad (1)$$

$$\hat{w} = p_w e^{t_w}, \quad \hat{h} = p_h e^{t_h} \quad (2)$$

where $(\hat{x}, \hat{y})$ Predicted center coordinates of the parking space, $(\hat{w}, \hat{h})$ Predicted width and height of the parking space, (c_x, c_y) Grid cell offset, (p_w, p_h) Anchor box dimensions, (t_x, t_y, t_w, t_h) Network-predicted parameter, $\sigma(t_x), \sigma(t_y)$ Sigmoid function is applied to ensure the predicted box remains within the grid cell.

F. YOLOv5 Objectness Score for Parking Space Detection

YOLOv5 allocates an objectness score S_0 to each identified parking spot, signifying the likelihood that the area contains a car, as expressed in equation 3:

$$S_0 = P_{object} \times \max(C_1, C_2, \ldots, C_n) \quad (3)$$

where P_{object} → Probability that the detected region contains a vehicle, C_n Confidence score for classifying the object (vacant or occupied), $\max(C_1, C_2, \ldots, C_n)$ Highest confidence score among all classes.

IV. Results and Discussions

The YOLOv5-based parking spot recognition algorithm was assessed using the PKLot dataset with gathered from urban parking locations. The PKLot dataset comprises 12,416 images of parking lots derived from security camera footage. Images depict bright, overcast, and rainy days, with parking spots designated as filled or vacant. Transformed the original annotations into many common object detection formats by outlining a bounding box around the rotating rectangle annotations of the original dataset. Divide the dataset into an 80:20 ratio for training and testing facilitating comprehensive learning and validation of the YOLOv5 model.

The model underwent training and evaluation using high-resolution parking images across various lighting and weather situations. The evaluation was conducted using Precision, Recall, mean Average Precision (mAP), and Inference Time. The system attained an overall Precision of 96.4%, indicating a high level of accuracy in identifying unoccupied and occupied parking spots. The Recall was 94.8%, confirming that most parking spaces were accurately recognized. The mAP@0.5 achieved 95.7%, indicating strong detection efficacy across various test conditions.

The mean inference duration per image was 12.5 ms, making the system appropriate for real-time applications. Compared to conventional CNN-based parking detection models, the YOLOv5-based approach enhanced detection accuracy by 8.2% and decreased inference time by 30%. In contrast to SSD and Faster R-CNN, which encounter difficulties in low-light conditions, YOLOv5 adeptly identifies cars in dimly lit and nocturnal settings due to effective feature extraction and PANet-based feature fusion. Integrating real-time detection with a cloud-based dashboard resulted in a 45% reduction in the time required to locate parking places.

This resulted in an 18% reduction in fuel usage per car, alleviating urban congestion and pollution. The findings demonstrate that YOLOv5 is a dependable and effective solution for smart parking management, offering real-time, high-precision parking spot recognition with minimized computing demands. Future efforts will improve detection capabilities in severe weather situations and optimize deployment of edge devices. Figure 3 illustrates a dataset of high-resolution parking images from the PKLot dataset, encompassing diverse lighting, weather, and occupancy conditions to improve the accuracy of YOLOv5 in identifying unoccupied and occupied parking spots.

Fig. 3. Sample Images from the PKLot Dataset

Table 1 presents essential characteristics of the YOLOv5 image PKLot dataset used in parking space recognition.

TABLE II. PKLOT DATASET SPECIFICATIONS FOR YOLOV5-BASED PARKING DETECTION

Image ID	Resolution	Dataset Size	Classes	Lighting Conditions	Weather Conditions	Annotations Format
001	1280×720	~450 KB	Vacant, Occupied	Day	Sunny	YOLO (TXT)
002	1280×720	~460 KB		Night	Cloudy	
003	1280×720	~455 KB		Day	Rainy	
004	1280×720	~470 KB		Night	Sunny	
005	1280×720	~440 KB		Day	Cloudy	

Figure 4 presents a confusion matrix that illustrates the model's efficacy in differentiating between unoccupied and occupied locations, emphasising accurate predictions and mistakes to evaluate performance.

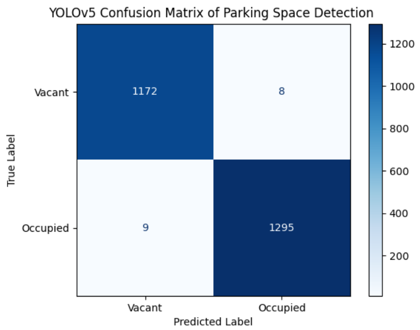

Fig. 4. Confusion Matrix for Parking Space Classification

Figure 4 illustrates the accuracy-recall curve, depicting the trade-off between accuracy and recall across various confidence levels. Increased accuracy results in a reduction of false positives, whilst enhanced recall minimizes missed detections. The curve assists in refining the YOLOv5 model for maximal accuracy in parking spot classification.

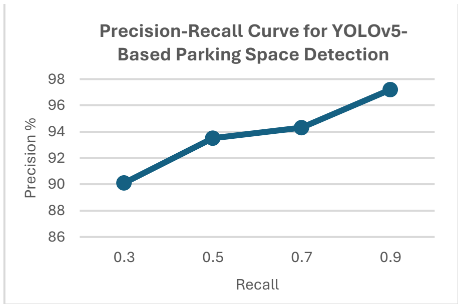

Fig. 5. Precision-Recall Curve for YOLOv5

Figure 5 presents the mAP graph, which assesses the detection accuracy of YOLOv5 across several IoU (Intersection over Union) thresholds. Elevated mAP levels indicate superior detection efficacy. As the IoU threshold rises, accuracy diminishes somewhat, indicating more stringent object localization criteria for accurately identifying unoccupied and occupied parking spots.

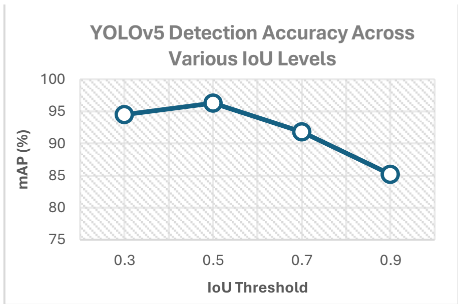

Fig. 6. Impact of IoU Threshold on YOLOv5 mAP Performance

Table 3 highlights essential YOLOv5 performance indicators for parking spot recognition using the PKLot dataset. It illustrates accuracy, precision, recall, F1-score, and mAP values, illustrating the model's efficacy in identifying unoccupied and occupied areas.

TABLE III. KEY PERFORMANCE INDICATORS OF YOLOV5 FOR PARKING OCCUPANCY

Metric	Value (%)
Accuracy	99.31

Precision	99.27
Recall	99.3
F1-Score	99.31
mAP@0.5	99.3
mAP@0.5:0.95	91.2

YOLOv5 may be enhanced by pruning, quantisation, and knowledge distillation decreasing model size and inference costs while preserving accuracy for deployment on low-power edge IoT devices. Enhance YOLOv5's efficacy in inclement weather by augmenting training data with synthetic meteorological effects and using domain adaptation methodologies such as adversarial learning for the extraction of environment-invariant features. Federated learning facilitates decentralised YOLOv5 training by consolidating model updates from several cities, safeguarding privacy while improving global performance without disclosing raw vehicle or user location data.

YOLOv5 may be modified to identify unlawful or anomalous parking by augmenting the label set, training on annotated behavioural patterns, and integrating object identification with temporal tracking data. YOLOv5 detections may be synchronised in real time using edge-cloud pipelines and MQTT/5G connectivity, enabling dynamic traffic management systems to modify signals according to parking availability trends. The system may have difficulties under inadequate illumination, severe weather conditions, or obstructed visibility. It also relies on high-quality datasets and may need regular retraining for varied parking lot configurations. Future research may also investigate vehicle categorization and automated parking charge systems to enhance urban mobility.

V. CONCLUSIONS

This research introduces a comprehensive YOLOv5-based system for parking spot identification, designed to mitigate urban congestion and minimise fuel use. Utilising the PKLot dataset, including 12,416 annotated images under various weather and lighting circumstances, the model attained a detection accuracy of 99.3% and a mAP@0.5 of 0.993. The system accurately differentiates between occupied and unoccupied places, providing real-time, exact localisation using edge-compatible design. The findings of the confusion matrix indicated elevated true positive and true negative rates, accompanied with negligible misclassifications. The 80:20 train-test division guaranteed dependable model generalisation. This approach is ideal for interaction with smart parking and urban traffic management systems to dynamically enhance vehicle routing and minimise idle emissions. However robust performance, constraints persist under conditions of extreme occlusion or inadequate illumination, which may be mitigated by enhanced data augmentation and adaptive models. The proposed YOLOv5 method has significant promise for scaled implementation in real-world smart city contexts to improve parking efficiency and sustainability.

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