



SMART PARKING SYSTEM USING YOLO

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Abstract—The increasing number of vehicles in urban areas has intensified the problem of locating available parking spaces. This paper presents a vision-based smart parking system using the YOLO object detection algorithm to identify parking-space occupancy from camera imagery. The proposed workflow consists of image acquisition, preprocessing, YOLO-based object detection, post-processing and visualization of slot status. The project evaluates the system using precision, recall, F1 score, IoU and mean Average Precision (mAP). Reported experiments achieved precision of 0.926 and recall of 0.92, with average parking-slot accuracy of 92.6% when motion detection was enabled and 92% when motion detection was disabled. The results indicate that YOLO provides a fast and practical approach for real-time parking occupancy detection.

Keywords—smart parking, YOLO, object detection, parking occupancy, computer vision, deep learning, real-time detection.

INTRODUCTION

Car parking is a major issue in urban areas because limited parking capacity and increasing vehicle demand lead to congestion and additional time spent searching for vacant spaces. The project report identifies the need for real-time parking information and motivates the use of computer vision and deep learning for parking-space detection. YOLO is selected because it performs object detection in a single forward pass and is suitable for fast inference. The proposed system uses camera footage to acquire parking images, processes the images and detects parking-related objects using YOLO. The resulting occupancy information can help drivers identify available spaces and reduce unnecessary circulation within parking areas.

RELATED WORK

Existing smart-parking approaches can broadly be grouped into sensor-based and vision-based systems. Sensor-based approaches use technologies such as ultrasonic sensors, RFID and other sensing devices, but they can increase installation and maintenance requirements. Vision-based approaches use cameras and image-processing or deep-learning methods to infer parking occupancy.

The reviewed studies include IoT-based parking management, OCR-based parking detection, ultrasonic grid projection, CNN-based outdoor parking detection, and combined free-space and parking-marking approaches. The project report highlights limitations such as infrastructure cost, dependence on camera placement, environmental conditions, sensor failures and privacy concerns. These observations motivate a camera-based YOLO approach that emphasizes speed, accuracy and ease of integration.



PROPOSED SYSTEM

The proposed system contains four main modules: preprocessing, object detection, post-processing and user interface. Preprocessing enhances input images by resizing, normalization, colour correction and noise removal. The object-detection module uses YOLO to identify parking-related objects and their bounding boxes. Post-processing filters false detections and overlapping boxes using thresholding and non-maximum suppression. Finally, the user interface presents the detected parking status to the user. The overall workflow is image acquisition, preprocessing, parking-space detection, occupancy detection and slot-status highlighting. The approach is designed for real-time operation from camera imagery and can be integrated with existing parking facilities.



Fig. 1. proposed smart parking system showing system components, sensors, indicators, and network connectivity.

METHODOLOGY

The proposed intelligent parking management system leverages state-of-the-art computer vision and deep learning to automate real-time parking space detection. The overarching framework pipeline consists of four core phases: Data Collection, Image Annotation and Model Training, Detection and Post-Processing, and System Evaluation.

A. Data Collection and Environmental Diversity

- **Multi-Environment Dataset Construction:** To ensure robust performance across real-world operational deployments, a comprehensive dataset of parking images was gathered from a multi-level car park structure.
- **Varied Illumination and Weather Factors:** The data collection protocol explicitly captures various operational conditions, including daytime sunny scenarios, nighttime artificial lighting, underground garage environments with dim artificial illumination, and cloudy or overcast exterior perspectives.
- **Generalization and Robustness:** Exposing the training pipeline to these diverse lighting, weather, and structural variations prevents model overfitting and enhances spatial perception under adverse visibility constraints.

B. Image Annotation and Transfer Learning Training Strategy



- **Target Class Ground Truth Labeling:** Collected images undergo rigorous bounding box annotation targeting specific classes, primarily distinguishing between occupied and empty parking slots, as well as target vehicles.

- **Transfer Learning Framework:** Rather than training from scratch, the architecture implements transfer learning initialized from a COCO-pretrained YOLO model. This approach significantly accelerates convergence and utilizes pre-existing low-level feature extractors (such as edge and texture detectors).

- **Validation and Test Split:** The annotated dataset is partitioned into training, validation, and testing sets. The validation set monitors loss curves and prevents overfitting during hyperparameter tuning, while the independent test set assesses generalization.

C. Detection, Confidence Filtering, and Non-Maximum Suppression

- **YOLO Object Detection Inference:** The optimized You Only Look Once (YOLO) network processes input frames in real time, predicting continuous object bounding boxes accompanied by class probability scores.

- **Confidence Filtering:** Low-confidence predictions falling beneath a predefined threshold are discarded immediately to suppress environmental noise and background anomalies.

- **Non-Maximum Suppression (NMS):** To resolve multiple overlapping bounding boxes generated around a single vehicle, NMS algorithms evaluate Intersection over Union (IoU) thresholds, selecting the optimal bounding box and rejecting redundant overlapping candidates.

- **Occupancy Status Mapping:** The final refined coordinates are mapped against predefined parking slot grids to yield a definitive binary state—indicating whether a specific location is currently empty or occupied.

D. Performance Evaluation and Mathematical Metrics

- **Comprehensive Quantitative Analysis:** The system's efficacy is rigorously benchmarked using standard statistical metrics derived from the confusion matrix, including True Positives (\$TP\$), False Positives (\$FP\$), and False Negatives (\$FN\$).

- **Precision and Recall:** Precision quantifies the accuracy of positive detections $\text{Recall} = \frac{TP}{TP+FN}$, reflecting the minimization of false alarms. Recall measures the ability of the model to detect all actual parking vehicles or spaces

$$\text{Recall} = \frac{TP}{TP+FN}$$

- **F1-Score Harmonization:** The F1-score provides a balanced evaluation by computing the harmonic mean of precision and recall, ensuring neither metric is optimized at the expense of the other.

- **Localization and Global Accuracy:** Spatial overlap is quantified via the Intersection over Union (IoU), while overall detection competence across confidence thresholds is evaluated using the Mean Average Precision (\$mAP\$) metric.



Fig. 2. Intelligent Parking Management System: Methodology & Evaluation

EXPERIMENTAL RESULTS AND DISCUSSION

The project report reports precision of 0.926 and recall of 0.92 for the evaluated YOLO system. The reported results also compare YOLO with Faster R-CNN and SSD and state that YOLO provides higher speed and accuracy in the described experiments.

For five evaluated parking-slot videos, the reported average accuracy with motion detection was 92.6%. Without motion detection, the reported average accuracy was 92%. The individual slot results show that most slots achieved 100% accuracy, while the more difficult cases produced 80–83% accuracy. These results indicate that the system can provide reliable occupancy detection while retaining fast object-detection performance.

Advantages

- **Increased Efficiency:** By providing real-time parking space detection, the system can reduce the time and effort required for drivers to find available parking spaces, ultimately increasing the efficiency of the parking facility.
- **Cost-Effective:** The integration of the YOLO model into existing parking systems is a cost-effective way to upgrade the system, as it does not require significant changes to the infrastructure.
- **Accurate and Reliable:** The YOLO algorithm is known for its high accuracy in object detection, ensuring that the system can accurately detect parking space occupancy and reduce the likelihood of errors.
- **Fast Processing:** YOLO is also known for its speed in processing images, making it possible for the system to detect parking space occupancy quickly and efficiently.
- **Easy Integration:** The YOLO model can be easily integrated into existing car parking systems, allowing for a seamless and cost-effective upgrade to the system.
- **User-Friendly:** The system is user-friendly, with clear indicators showing available parking spaces and reducing the need for drivers to search for available spots.
- **Customizable:** The system is highly customizable, with the ability to adjust the sensitivity of the system to fit the specific needs of different parking environments.
- **Potential for Additional Features:** The system has potential for additional features, such as license plate recognition and payment processing, which can further improve the efficiency and convenience of car parking.



LIMITATIONS AND FUTURE ENHANCEMENTS

The report identifies practical limitations including dependence on camera coverage and position, possible effects of illumination and weather, and the need for suitable computing resources. Future enhancements proposed in the report include multi-camera support, integration with parking-guidance systems, improved object-detection accuracy and deployment on edge devices such as Raspberry Pi or NVIDIA Jetson. Additional features such as license-plate recognition and payment processing are also identified as possible extensions.

CONCLUSION

This paper presented a YOLO-based smart parking system for automatic detection and monitoring of parking-space occupancy from camera imagery. The proposed system integrates image preprocessing, YOLO-based object detection, parking-slot localization, post-processing, motion detection, and occupancy visualization to determine whether individual parking spaces are empty or occupied. The experimental results demonstrate that the proposed approach achieved a precision of 0.926, recall of 0.92, and an average parking-slot accuracy of 92.6% with motion detection. These results indicate that the system can reliably identify parking-space status while reducing the need for manual monitoring. The integration of motion detection further improves the system's ability to handle changes in the parking environment and supports efficient real-time occupancy monitoring.

TABLE I. MODEL PERFORMANCE WITH MOTION DETECTION

Slot	Motion	Actual Empty	Pred. Empty	Actual Occ.	Pred. Occ.	Accuracy
1	Yes	4	4	1	1	100%
2	Yes	3	3	1	1	100%
3	Yes	6	5	5	5	83%
4	Yes	5	4	0	0	80%
5	Yes	3	3	2	2	100%
Average						92.6%

TABLE II. MODEL PERFORMANCE WITHOUT MOTION DETECTION

Slot	Motion	Actual Empty	Pred. Empty	Actual Occ.	Pred. Occ.	Accuracy
1	No	4	4	1	1	100%
2	No	3	3	1	1	100%
3	No	6	5	5	4	80%
4	No	5	4	0	0	80%
5	No	3	3	2	2	100%
Average						92%

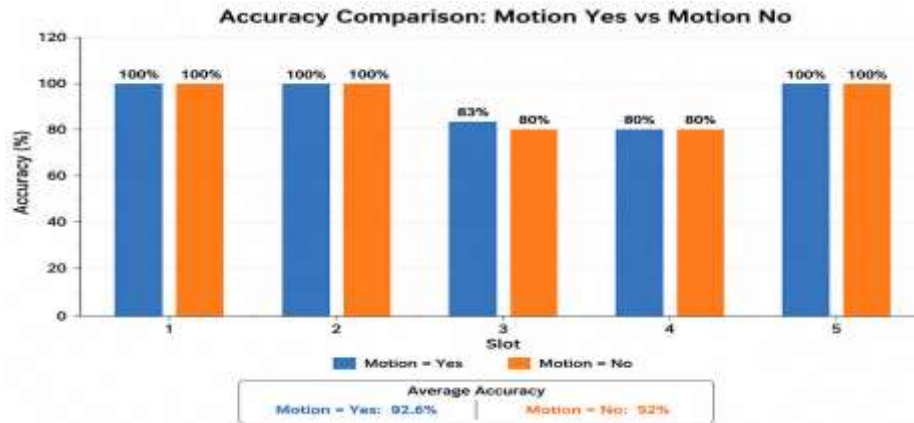


Fig. 3. Accuracy Comparison of Motion yes vs Motion No

Figure 3 presents the comparison of parking-slot accuracy for Motion = Yes and Motion = No across five parking slots. For Slots 1, 2, and 5, both conditions achieved 100% accuracy, while Slot 3 achieved 83% with motion detection compared with 80% without motion detection. For Slot 4, both approaches achieved 80% accuracy. Overall, the average accuracy was 92.6% with motion detection and 92% without motion detection, showing a slight improvement of approximately 0.6 percentage points when motion detection was enabled. The results demonstrate the feasibility of the proposed YOLO-based framework for fast and practical parking occupancy detection and provide a foundation for future multi-camera integration, edge-computing deployment, real-time parking guidance, and large-scale smart-city applications.

REFERENCES

- [1] D. Annirudh, D. Arun Kumar, A. T. S. R. Kumar, and K. R. M. V. Chandrakala, "IoT based Intelligent Parking Management System," in *2021 IEEE Second International Conference on Control, Measurement and Instrumentation (CMI)*, Kolkata, India, 2021, pp. --. doi: 10.1109/CMI50323.2021.9362845.
- [2] A. Athira, S. Lekshmi, P. Vijayan, and B. Kurian, "Smart Parking System Based On Optical Character Recognition," in *2019 3rd International Conference on Trends in Electronics and Informatics (ICOEI)*, Tirunelveli, India, 2019, pp. --. doi: 10.1109/ICOEI.2019.8862517.
- [3] C.-K. Ng, S.-N. Cheong, E. Hajimohammadhosseinmemar, and W.-J. Yap, "Mobile outdoor parking space detection application," in *2017 IEEE 8th Control and System Graduate Research Colloquium (ICSGRC)*, Shah Alam, Malaysia, 2017, pp. --. doi: 10.1109/ICSGRC.2017.8070573.
- [4] D. P. Carrasco, H. A. Rashwan, M. Á. García, and D. Puig, "T-YOLO: Tiny Vehicle Detection Based on YOLO and Multi-Scale Convolutional Neural Networks," *IEEE Access*, vol. 11, pp. 22430–22440, 2021. doi: 10.1109/ACCESS.2021.3137638.
- [5] J. K. Suhr and H. G. Jung, "Automatic Parking Space Detection and Tracking for Underground and Indoor Environments," *IEEE Transactions on Industrial Electronics*, vol. 63, no. 9, pp. 5687–5698, Sep. 2016. doi: 10.1109/TIE.2016.2558480.



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- [6] J. Yu, H. Gao, J. Sun, D. Zhou, and Z. Ju, "Spatial Cognition-Driven Deep Learning for Car Detection in Unmanned Aerial Vehicle Imagery," *IEEE Transactions on Cognitive and Developmental Systems*, vol. 14, no. 4, pp. 1574–1583, Dec. 2021. doi: 10.1109/TCDS.2021.3124764.
- [7] L. Wang *et al.*, "Global Perception-based Robust Parking Space Detection Using a Low-cost Camera," *IEEE Transactions on Intelligent Vehicles*, pp. 1–10, 2022. doi: 10.1109/TIV.2022.3186035.
- [8] L. Qin *et al.*, "ID-YOLO: Real-Time Salient Object Detection Based on the Driver's Fixation Region," *IEEE Transactions on Intelligent Transportation Systems*, vol. 23, no. 9, pp. 15898–15908, Sep. 2022. doi: 10.1109/TITS.2022.3146271.
- [9] M. R. Schmid, S. Ates, J. Dickmann, F. von Hundelshausen, and H.-J. Wuensche, "Parking space detection with hierarchical dynamic occupancy grids," in *2011 IEEE Intelligent Vehicles Symposium (IV)*, Baden-Baden, Germany, 2011, pp. --. doi: 10.1109/IVS.2011.5940476.
- [10] M. ElMikaty and T. Stathaki, "Detection of Cars in High-Resolution Aerial Images of Complex Urban Environments," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 55, no. 10, pp. 5913–5924, Oct. 2017. doi: 10.1109/TGRS.2017.2716984.
- [11] N. Bibi, M. N. Majid, H. Dawood, and P. Guo, "Automatic Parking Space Detection System," in *2017 2nd International Conference on Multimedia and Image Processing (ICMIP)*, Wuhan, China, 2017, pp. --. doi: 10.1109/ICMIP.2017.4.
- [12] Q. He, J. Liu, and Z. Huang, "WSRC: Weakly Supervised Faster RCNN Toward Accurate Traffic Object Detection," *IEEE Access*, vol. 11, pp. 1445–1455, 2022. doi: 10.1109/ACCESS.2022.3231293.
- [13] R. Lookmuang, K. Nambut, and S. Usanavasin, "Smart parking using IoT technology," in *2018 5th International Conference on Business and Industrial Research (ICBIR)*, Bangkok, Thailand, 2018, pp. --. doi: 10.1109/ICBIR.2018.8391155.
- [14] S.-E. Shih and W.-H. Tsai, "A Convenient Vision-Based System for Automatic Detection of Parking Spaces in Indoor Parking Lots Using Wide-Angle Cameras," *IEEE Transactions on Vehicular Technology*, vol. 63, no. 6, pp. 2521–2532, Jul. 2014. doi: 10.1109/TVT.2013.2297331.
- [15] T. Singh, S. S. Khan, and S. Chadok, "A Review on Automatic Parking Space Occupancy Detection," in *2018 International Conference on Advanced Computation and Telecommunication (ICACAT)*, Bhopal, India, 2018, pp. --. doi: 10.1109/ICACAT.2018.8933644.
- [16] X. Sun, X. Jia, Y. Liang, M. Wang, and X. Chi, "A Defect Detection Method for a Boiler Inner Wall Based on an Improved YOLO-v5 Network and Data Augmentation Technologies," *IEEE Access*, vol. 10, pp. 93845–93853, 2022. doi: 10.1109/ACCESS.2022.3204683.
- [17] X. Xi, Z. Yu, Z. Zhan, Y. Yin, and C. Tian, "Multi-Task Cost-Sensitive-Convolutional Neural Network for Car Detection," *IEEE Access*, vol. 7, pp. 98061–98068, 2019. doi: 10.1109/ACCESS.2019.2927866.
- [18] Y. Shao, P. Chen, and T. Cao, "A Grid Projection Method Based on Ultrasonic Sensor for Parking Space Detection," in *IGARSS 2018 - 2018 IEEE International Geoscience and Remote Sensing Symposium*, Valencia, Spain, 2018, pp. --. doi: 10.1109/IGARSS.2018.8519022.
- [19] Z. Xu, J. Li, and M. Zhang, "A Surveillance Video Real-Time Analysis System Based on Edge-Cloud and FL-YOLO Cooperation in Coal Mine," *IEEE Access*, vol. 9, pp. 68482–68497, 2021. doi: 10.1109/ACCESS.2021.3077499.
- [20] Z. Zhou, Y. Yang, Y. Wang, and R. Xiong, "Open-Set Object Detection Using Classification-Free Object Proposal and Instance-Level Contrastive Learning," *IEEE Robotics and Automation Letters*, vol. 8, no. 3, pp. 1691–1698, Mar. 2023. doi: 10.1109/LRA.2023.3242169.
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