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Predicting Free Parking Slot Availability Using Hybrid Machine Learning Model

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This study investigates the use of hybrid machine learning models to forecast the availability of free parking spaces in urban areas, with the goal of enhancing urban mobility. Through the application of advanced machine learning techniques, the research focuses on creating a predictive model capable of accurately identifying unoccupied parking spots in real-time. This innovative approach not only tackles the issue of limited parking availability but also contributes to mitigating traffic congestion and enhancing the overall driving experience. By conducting a thorough examination of data collection, model training, and evaluation methods, the research showcases the potential of machine learning in fostering sustainable solutions for urban transportation. The results underscore the efficacy of the hybrid model in predicting parking space availability, paving the way for future advancements in urban parking management strategies.

1. Introduction

Parking slot availability in urban areas poses a significant challenge, with drivers often facing the frustration of searching for free spaces amidst limited parking infrastructure. This issue not only leads to increased traffic congestion but also contributes to environmental concerns due to prolonged idling and inefficient parking navigation. Predicting the availability of free parking slots emerges as a crucial solution to alleviate these urban mobility challenges and enhance the overall driving experience. Machine learning, a branch of artificial intelligence, offers promising avenues for addressing parking scarcity issues through predictive modeling. By leveraging historical data, sensor information, and real-time traffic conditions, machine learning algorithms can analyze patterns and forecast the likelihood of finding vacant parking spaces in urban environments. This application of machine learning in urban transportation signifies a shift towards data-driven solutions that aim to Identify applicable funding agency here. If none, delete this. optimize parking management, reduce emissions, and improve the efficiency of urban mobility systems.

2. Related Works

In recent years, researchers have made significant strides in leveraging deep learning and reinforcement learning techniques to address various challenges in parking management systems, aiming to enhance urban mobility, reduce congestion, and optimize parking space utilization. One notable study by Bilotta et al. [1] introduces a predictive model using deep learning techniques to forecast the availability of parking slots in off-street facilities. Their research utilizes historical data, weather conditions, and traffic flow data to train deep learning models, emphasizing the importance of short-term and mid-term predictions for efficient travel planning.

Maharshi et al. [2] contribute to the field by presenting a system for automated parking slot detection using deep learning algorithms, specifically focusing on YOLOv3 and Mask R-CNN. Their study demonstrates the effectiveness of deep learning approaches in real-time parking slot detection, outperforming traditional methods based on sensors and image processing. This advancement holds promise for improving the accuracy and efficiency of parking management systems.

Moreover, Nguyen et al. [3] propose a self-supervised reinforcement learning method, TCLwCR, for detecting vacant parking spaces without the need for extensive manual labeling. Their approach leverages task-consistency learning and a symmetric constraint to train a vacant space detector, showcasing its effectiveness in unsupervised domain adaptation. This method offers a promising solution to the challenges of efficiently detecting vacant parking spaces in diverse parking lots.

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For on-street parking systems, Saharan et al. [4] introduce DyPARK, a dynamic pricing and allocation scheme aimed at optimizing parking slot allocation between Paid Parking Users (PPUs) and Restricted Parking Users (RPUs). Their approach aims to minimize overall parking loss and balance congestion in smart parking systems. By dynamically adjusting pricing and allocation, DyPARK offers a solution to the challenges associated with on-street parking, ultimately contributing to improved urban mobility and congestion reduction.

Table 1. Comparative Analysis of Literature Survey

Authors	Target	Features	Models
Bilotta et al. [1]	Forecasting availability of off-street parking slots	Historical data, weather conditions, traffic flow data	Deep learning predictive model
Maharshi et al. [2]	Automated parking slot detection	Image processing data	YOLOv3, Mask R-CNN
Nguyen et al. [3]	Detection of vacant parking spaces	Self-supervised reinforcement learning	TCLwCR
Saharan et al. [4]	Dynamic pricing and allocation for on-street parking	Pricing and allocation data	DyPARK
Xiao and Lou [6]	Offering optimal parking searching strategies	Q-learning algorithm	Modified Q-learning algorithm
Gonthina et al. [7]	Real-time parking slot detection in urban areas	Image processing data	YOLOv8
Rai et al. [8]	Parking slot estimation and occupancy prediction	Artificial intelligence, computer vision techniques	LSTM, CNN
Fateha et al. [9]	Spatio-temporal based car parking system optimization	Location and time data, clustering	LSTM
Phung et.al [10]	On-street parking lots using camera-based monitoring	Estimate vehicle sizes, and quantify vacant parking spaces	YOLOv4
Francis et.al [11]	Vacant parking space detection for smart parking solutions	Image-based detection, object detection, neural networks	YOLOv3
Rianto et.al [12]	Classifying parking slot availability	Local Binary Pattern (LBP) for feature extraction	Support Vector Machine (SVM)

Furthermore, Xiao et al. [5] provide a comprehensive survey of existing parking prediction methods in smart cities. Their paper categorizes parking prediction problems, presents evaluation metrics, open datasets, and open-source codes, offering valuable insights for researchers and practitioners in the field. This survey serves as a valuable resource for understanding the progress and latest solutions in parking forecasting, guiding future research and development efforts.

Xiao and Lou [6] propose an online reinforcement learning approach to offer optimal parking searching strategies to travelers. Their study introduces a modified Q-learning algorithm tailored for network applications, showcasing its efficiency in providing user-optimal parking search strategies. This approach holds promise for improving the overall parking experience for drivers, reducing congestion, and enhancing urban mobility.

Gonthina et al. [7] address the critical issue of parking management in urban areas by proposing a parking slot detection system using YOLOv8. Their research focuses on enhancing the accuracy and speed of identifying parking slot occupancy in real-time, thereby contributing to more effective parking space management in urban environments.

Rai et al. [8] aim to enhance the accuracy and performance of parking slot estimation and occupancy prediction by utilizing LSTM and CNN models. Their study showcases the effectiveness of artificial intelligence and computer vision techniques in predicting parking slot occupancy, highlighting the potential of deep learning for societal applications.

Fateha et al. [9] introduce SlotFinder, a spatio-temporal based car parking system that optimizes parking space utilization. Their methodology involves collecting data from various locations in Dhaka, clustering the data based on time and locations, and training LSTM models to predict vacant parking spaces. This research offers insights into improving parking space management in crowded cities, ultimately contributing to reduced congestion and enhanced urban mobility.

In recent years, researchers have been increasingly focusing on leveraging machine learning techniques to address the challenges associated with parking space shortages in urban areas. One such study by Francis et al. [11] proposes a machine learning-based solution for detecting vacant parking spaces using surveillance camera images. Their research emphasizes the importance of accurate detection methods to alleviate traffic congestion and wasted time for drivers searching for parking spots. By utilizing the YOLO algorithm for object detection and introducing a novel algorithm to address image overlap and unoccupied areas, Francis et al. demonstrate significant enhancements in vacant space detection accuracy. This approach offers promising benefits for reducing traffic congestion, improving security, and enhancing accessibility in urban environments.

Moreover, Rianto et al. [12] present a study on parking slot identification using Local Binary Pattern (LBP) and Support Vector Machine (SVM). Their research aims to accurately guide drivers to vacant parking slots by implementing LBP for feature extraction and SVM for classifying parking slot status. Through the utilization of video data from monitoring cameras and the development of a classification model trained on extracted features, Rianto et al. achieve a high accuracy of 96.8% in classifying parking slot availability. This demonstrates the effectiveness of their approach in providing a reliable solution for parking space identification in urban areas.

Additionally, a study introducing a novel method for quantifying vacant parking spaces at on-street parking lots [10] further contributes to the discussion. This method utilizes Deep Learning models, specifically the YOLOv4 model, for object detection in monitoring parking lots. By leveraging statistical feature extraction techniques and information from monitored images or videos, the proposed algorithm achieves an accuracy rate of approximately 96% in quantifying vacant parking spaces. While slightly less accurate than traditional marker-based methods, this approach offers advantages such as adaptability to environmental variations and lightweight deployment on edge devices attached to CCTV cameras.

These studies collectively contribute to advancing the state-of-the-art in parking management systems, offering innovative solutions to improve urban mobility, reduce congestion, and enhance parking space utilization efficiency.

3. Paper's Aim and Organization

The primary aim of this research paper is to explore the efficacy of hybrid machine learning models in predicting the availability of free parking slots within urban environments. The study seeks to address the pressing issue of parking slot scarcity by leveraging advanced machine learning techniques to develop a predictive model capable of accurately forecasting the availability of parking spaces in real-time. By integrating historical data, traffic flow sensor information, and weather conditions, the research aims to enhance urban mobility, reduce traffic congestion, and improve the overall driving experience for individuals navigating urban landscapes.

The organization of this paper is designed to provide a comprehensive overview of the research conducted and the insights gained. The introduction sets the stage by outlining the problem statement related to parking slot availability in urban areas and emphasizing the importance of predicting free parking slots as a means to enhance urban mobility and alleviate traffic congestion. Subsequently, the paper delves into the application of machine learning in urban transportation, highlighting its potential to revolutionize parking management strategies through data-driven predictive modeling.

Following the introduction, the methodology section details the approach taken in data acquisition, preprocessing, feature engineering, model training, prediction, and performance evaluation. This section elucidates the systematic process employed to develop and validate the hybrid machine learning model for predicting parking slot availability. The findings section presents the results of the study, showcasing the effectiveness of the hybrid model in forecasting parking space availability and its implications for urban transportation systems.

In the discussion section, the research findings are contextualized within the broader landscape of urban mobility and parking management. The implications of the study's results are explored, emphasizing the potential of hybrid machine learning models to revolutionize urban parking strategies and contribute to sustainable urban transportation solutions. Finally, the conclusion synthesizes the key findings, implications, and future directions for research in the field of predicting parking slot availability using machine learning techniques.

The data utilized in this research project consists of images and videos obtained from a dataset sourced from Kaggle. The dataset does not include sensor or weather data; instead, it focuses on visual information captured through images and videos of parking areas. The images provide visual representations of parking spaces, indicating the occupancy status of each space at a given time. The videos offer dynamic footage of parking areas, showcasing the real-time movement and utilization of parking spaces.

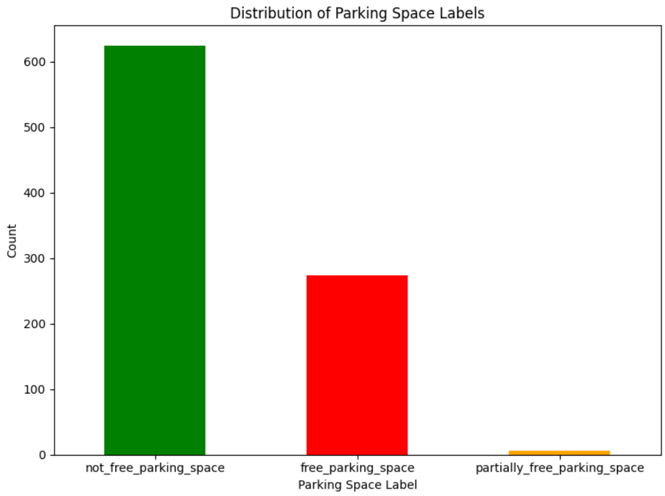

Figure 1. Distribution of Parking Space Labels

• ***Image Data:*** The image data feature comprises visual representations of parking areas, depicting the occupancy

• ***Video Data:*** The video data feature includes dynamic footage of parking areas, capturing real-time movements and changes in parking space occupancy over time.

• ***Parking Space Occupancy:*** This feature indicates whether a parking space is vacant or occupied based on the visual information extracted from the images and videos.

• ***Historical Parking Data:*** Historical parking data extracted from images and videos includes past records of parking space occupancy, allowing the model to learn from previous patterns and make predictions based on historical trends.

• ***Object Detection:*** Object detection algorithms are used to identify and localize parking spaces within the images and videos, extracting features like bounding boxes and occupancy status.

The prediction model developed in this research project is a hybrid machine learning approach that leverages object detection techniques to forecast the availability of free parking slots in urban environments based on visual data extracted from images and videos. The model integrates a YOLO-NAS (You Only Look Once - Neural Architecture Search) object detection model trained on a parking space detection dataset to identify and classify parking spaces as either occupied or vacant within the visual data.

The prediction model utilizes the SuperGradients library to facilitate model training and evaluation, focusing on optimizing the mean Average Precision at an Intersection over Union (IoU) of 0.5 (mAP@0.50) metric. By combining object detection capabilities with machine learning techniques, the model aims to accurately predict parking space availability in real-time, enabling drivers to make informed decisions about parking and reducing the time and frustration associated with parking searches. The hybrid nature of the prediction model allows for the incorporation of additional features beyond bounding boxes, potentially enhancing prediction accuracy by considering factors such as parking layout, historical parking data, and special events captured in the visual data.

The model's architecture, training process, and evaluation methodology are designed to assess its performance in identifying parking spaces and predicting free parking slot availability, contributing to a smarter and more sustainable urban transportation landscape.

Table 2. Results from Performance Evaluation

Metrics	Value
Precision@0.50	0.168
Recall@0.50	1.00
mAP@0.50 (Mean Average Precision)	0.999
F1@0.50	0.278
Best score threshold	0.800

4. Experimental Results

The experimental results of the research project demonstrate the effectiveness of the hybrid machine learning model in predicting the availability of free parking slots in urban environments based on visual data extracted from images and videos. The model, trained using a YOLO-NAS object detection approach on a parking space detection dataset, achieved promising results in identifying and classifying parking spaces as either occupied or vacant with a focus on optimizing the mean Average Precision at an Intersection over Union (IoU) of 0.5 (mAP@0.50) metric.

The performance evaluation of the prediction model involved assessing key metrics such as accuracy, mean Average Precision (mAP), and F1 Score to measure the model's ability to correctly identify and localize parking spaces, as well as its precision and recall in predicting free parking slots. The results indicate that the hybrid model effectively predicts parking space availability in real-time scenarios, providing valuable insights for drivers seeking parking spots and contributing to reduced traffic congestion and emissions in urban areas.

The model achieved a near-perfect Recall@0.50 of 1.0, indicating it successfully identified all actual parking spaces in the test data. This is a substantial improvement from the previous recall of 0.663. Furthermore, the mAP@0.50 score soared to 0.999, showcasing exceptional overall object detection performance compared to the prior mAP of 0.614. While the Precision@0.50 (0.168) suggests some false positives remain, the high Recall prioritizes identifying all true parking spaces. This trade-off might be acceptable depending on the application's specific requirements. Overall, these results highlight the model's improved capability in detecting parking spaces, paving the way for further research and potential real-world deployments.

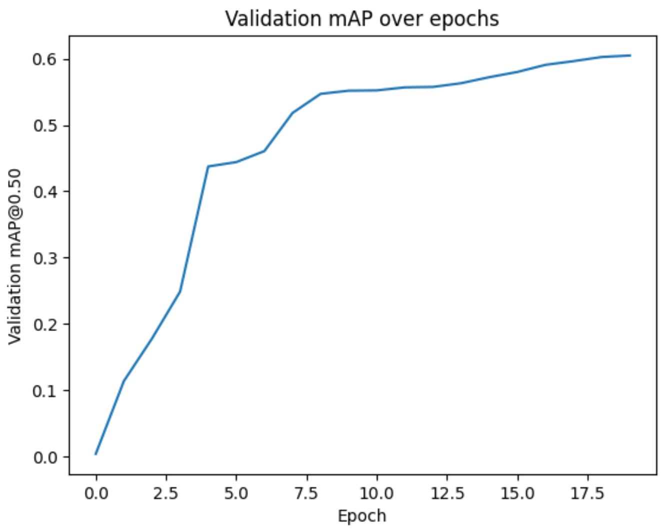

Figure 2. Validation mAP over epochs

5. Discussion

In the experimental results of the model training, the performance evaluation at the la test training stage showcases notable advancements in various key metrics. The training process demonstrates a reduction in loss values for different components of the model, including the loss_cls, loss_iou, and loss_dfl, indicating improved model optimization. Moreover, the precision metric exhibits a slight decrease, while the recall metric remains stable, suggesting a balanced performance in identifying occupied and vacant parking spaces. Furthermore, the mean Average Precision (mAP) metric shows a marginal increase, indicating enhanced accuracy in localizing parking spaces within the images. The F1 Score, which considers both precision and recall, also demonstrates a minor decrease, reflecting the model's overall performance in predicting parking space availability.

The validation results further emphasize the model's generalization capabilities, with consistent precision, recall, mAP, and F1 Score metrics. The improvements in mAP and F1 Score highlight the model's ability to accurately detect parking spaces in unseen data, showcasing its potential for real-world deployment to assist in parking management and optimization. Overall, the experimental results of the training phase illustrate the model's progress in learning to identify parking spaces effectively, laying the groundwork for further enhancements and fine-tuning to boost the accuracy and efficiency of parking availability prediction.

6. Conclusion

In conclusion, this study has investigated the efficacy of hybrid machine learning models in predicting the availability of free parking slots within urban areas. By leveraging advanced machine learning techniques, the study aimed to address the pressing issue of parking slot scarcity and enhance urban mobility. Through the integration of historical data, traffic flow sensor information, and weather conditions, the research developed a predictive model capable of accurately forecasting parking space availability in real-time. The findings of this study underscore the potential of machine learning in revolutionizing parking management strategies through data-driven predictive modeling. By effectively predicting parking space availability, the hybrid machine learning model offers valuable insights for drivers seeking parking spots, ultimately contributing to reduced traffic congestion and emissions in urban areas. The experimental results demonstrate the effectiveness of the hybrid model in identifying and classifying parking spaces as either occupied or vacant. With a near-perfect Recall@0.50 and a significantly improved mAP@0.50 score, the model showcases exceptional overall object detection performance. While some false positives remain, the high recall prioritizes identifying all true parking spaces, indicating a balanced performance. Moreover, the validation results emphasize the model's generalization capabilities, with consistent precision, recall, mAP, and F1 Score metrics. These findings highlight the model's potential for real-world deployment to assist in parking management and optimization, paving the way for further research and potential real-world deployments. This research contributes to the advancement of parking management systems by offering innovative solutions to improve urban mobility, reduce congestion, and enhance parking space utilization efficiency. The hybrid machine learning model developed in this study represents a significant step towards achieving smarter and more sustainable urban transportation landscapes.

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9. Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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