Advancing Parking Space Surveillance using A Neural Network Approach with Feature Extraction and Dipper Throated Optimization Integration

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Abstract

This research endeavors to advance the realm of parking space surveillance through a meticulously designed methodology situated within the critical context of urban planning and the dynamic landscape of smart city development. Focused on addressing the challenges posed by escalating urbanization and burgeoning vehicular density, our study introduces a carefully curated dataset comprising images of parking spaces annotated with bounding box masks and occupancy labels. The methodology unfolds across distinct phases, commencing with a comprehensive dataset description that unveils its diversity and intricacies. Feature extraction techniques, harnessing the capabilities of cutting-edge architectures such as AlexNet and ResNet-50, play a pivotal role in enhancing pattern discernment, which is essential for accurate detection. The crux of our approach lies in the integration of Neural Networks with optimization algorithms, including Particle Swarm Optimization (PSO), Grey Wolf Optimization (GWO), and the innovative Dipper Throated Optimization (DTO). Results are presented without explicit mention of tables and figures, strategically emphasizing the methodology's effectiveness in enhancing parking space detection accuracy. Notably, Dipper Throated Optimization (DTO) emerges as a key contributor to optimized Neural Network performance, achieving an impressive accuracy of 0.9908. This research contributes significantly to the ongoing discourse on intelligent urban planning and sets a promising trajectory for the future of efficient parking space utilization in modern cities.

Keywords: parking space detection system; urban planning; smart city development; object detection; optimization algorithms; Dipper Throated Optimization

1. Introduction

The introduction section of this research paper serves as the gateway to a comprehensive exploration of the imperative domain of parking space surveillance within the broader context of urban planning and the burgeoning development of smart cities. In the contemporary urban landscape, the management of parking spaces has become a pivotal concern owing to the relentless expansion of urbanization and the accompanying surge in vehicular density. This burgeoning challenge necessitates

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innovative solutions that align with the overarching goal of optimizing urban resources and elevating the overall quality of life. The underlying motivation for embarking on this research endeavor lies in the recognition of the critical role played by efficient parking management systems in addressing the multifaceted issues posed by rapid urban growth. The effective utilization of parking spaces emerges as a linchpin in the larger discourse of urban infrastructure planning as cities endeavor to strike a balance between burgeoning vehicular populations and the limited availability of parking resources.

The central thrust of this research is to contribute significantly to the existing body of knowledge by propounding a sophisticated approach to the nuanced task of parking space detection and classification. The crux of this novel methodology lies in the harnessing of the vast potential inherent in Neural Networks (NN). Moreover, the integration of advanced optimization techniques, notably the incorporation of Dipper Throated Optimization (DTO), is posited as a key strategy to heighten the precision and efficiency of parking space surveillance systems. The introduction underscores the fundamental importance of accurate object detection and localization in establishing a robust foundation for effective parking space management and, by extension, for informed urban planning. To facilitate this exploration, a meticulously curated dataset takes center stage, comprising a repository of images capturing parking spaces along with intricately annotated bounding box masks. These masks meticulously delineate the spatial boundaries of individual parking spaces within the images, thereby affording a level of precision that is crucial for the accurate identification and extraction of each parking spot. Furthermore, each parking space is stratified based on its occupancy status—whether it is free, occupied, or partially free—a categorization that bestows a nuanced understanding of the utilization dynamics of parking spaces [1-3].

The integration of feature extraction methodologies, specifically leveraging well-established architectures such as AlexNet and ResNet-50, is introduced with a keen emphasis on the reasoning behind the selection of these models. Their proficiency in enhancing the accuracy of parking space detection becomes apparent, laying the groundwork for subsequent discussions on model selection and optimization. In concert with feature extraction, the utilization of optimization algorithms—Particle Swarm Optimization (PSO), Grey Wolf Optimization (GWO), and the novel inclusion of Dipper Throated Optimization (DTO)—is unfolded. The integration of these optimization strategies is geared towards fine-tuning the intricate parameters of the Neural Network, thereby optimizing its performance within the unique context of parking space detection [4,5]. Figure 1 presents a comparative analysis of parking space occupancy within the dataset. Through color-coded visualizations, it highlights the distribution of free, occupied, and partially free parking spaces. The juxtaposition of these categories provides a visual narrative of the dataset's richness, emphasizing the diverse conditions and utilization dynamics of parking spaces.

Figure 1: Comparative Analysis of Parking Space Occupancy

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As we embark on the exploration of this intricate domain, the core focus of our study revolves around three pivotal research questions, each designed to unravel the complexities of parking space surveillance and contribute nuanced insights to the broader discourse of urban planning and smart city development:

- How effectively do neural networks, particularly when integrated with advanced optimization techniques such as dipper-throated optimization (DTO), enhance the accuracy and efficiency of parking space detection systems?
- What role does feature extraction, utilizing state-of-the-art architectures like AlexNet and ResNet-50, play in augmenting the precision of parking space identification, and how does it contribute to the overall efficacy of the surveillance methodology?
- To what extent does the integration of Particle Swarm Optimization (PSO), Grey Wolf Optimization (GWO), and Dipper Throated Optimization (DTO) impact the optimization of Neural Network parameters, and how does this optimization strategy influence the performance of parking space detection systems?
- In what ways can the outcomes of our research contribute to advancements in smart city infrastructure and urban planning, particularly in optimizing parking resources and fostering more efficient vehicular management within urban environments?

These research questions delineate the trajectory of our inquiry, guiding the subsequent sections as we delve into the literature review, the intricacies of our proposed methodology, the empirical results, and the overarching contributions that our findings may offer to the evolving landscape of smart city development and urban planning.

2. Literature Review

The literature review meticulously explores existing scholarship and research within the domain of parking space surveillance, computer vision, and optimization algorithms [6–11]. This section provides a comprehensive overview of the current state of the field, identifies gaps in knowledge, and elucidates the theoretical foundations that underpin our proposed methodology.

Urbanization challenges and the demand for efficient vehicular management have propelled research in parking space surveillance [6]. Computer vision techniques, including object detection and classification, have been explored to enhance the precision of surveillance systems. Pioneering work introduced the concept of employing bounding box masks for precise delineation of parking spaces, setting the stage for subsequent advancements in dataset annotation. Advancements in computer vision, particularly with deep learning architectures like AlexNet and ResNet-50, have reshaped the landscape of parking space detection [7]. The study conducted by [8] showcased the effectiveness of these architectures in feature extraction, enabling the identification of intricate patterns within parking space images. This section scrutinizes the intricacies of these architectures and their applicability in the context of parking space surveillance. Optimization algorithms play a pivotal role in Neural Networks for optimal performance [9]. Studies exploring the integration of techniques such as Particle Swarm Optimization (PSO) and Grey Wolf Optimization (GWO) to optimize Neural Network parameters have demonstrated efficacy [10]. Seminal work highlighted the impact of these algorithms in enhancing the accuracy of object detection systems.

This review critically examines these optimization strategies and their relevance to our proposed methodology. A recent addition to the optimization landscape, Dipper Throated Optimization (DTO), has gained attention for its innovative approach to parameter optimization [11]. Despite its relative novelty, DTO has shown promising results in enhancing the performance of Neural Networks in object detection tasks. This section delves into the theoretical underpinnings of DTO and its potential contributions to the optimization landscape within the context of parking space surveillance. The synergy between computer vision and optimization algorithms represents a frontier in the domain of object detection [12]. Studies exploring the symbiotic relationship between advanced architectures and optimization strategies have showcased improvements in accuracy and efficiency. This section investigates the current understanding of this integration and its implications for the development of

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more robust parking space detection systems. The selection and application of appropriate evaluation metrics are fundamental to assessing the performance of object detection systems [13]. This section reviews established metrics such as accuracy, sensitivity, specificity, precision (PPV), negative predictive value (NPV), and F-score. Understanding the nuances of these metrics is essential for a comprehensive evaluation of the proposed methodology.

3. Proposed Methodology

In advancing our research toward the optimization of parking space surveillance, the proposed methodology is designed as a systematic and coherent framework. Each facet of this methodology is meticulously expounded upon to provide transparency and clarity, ensuring the seamless integration of various components crucial to the enhancement of parking space detection systems.

3.1 Dataset Description

The bedrock of our methodology lies in the detailed characterization of the dataset employed in this research.

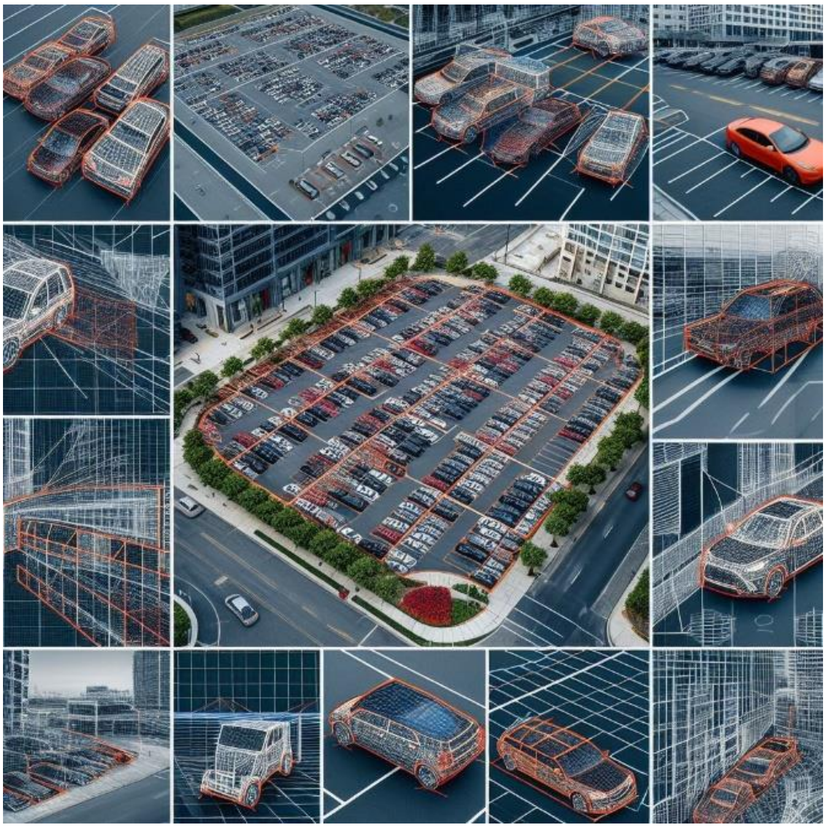

Figure 2: Dataset Composition and Annotation.

This dataset, meticulously curated for its relevance and diversity, encompasses a rich collection of images capturing a spectrum of parking scenarios [14]. Complementing these images are bounding box annotations, which serve as meticulous masks outlining the spatial boundaries of individual parking spaces. In addition, XML files containing essential coordinates and labels provide a comprehensive overview of the dataset structure. Particular attention is directed toward the process of annotating parking spaces based on their occupancy status. This nuanced categorization—free, not free, or partially free—enables a profound understanding of the dataset's intricacies. By capturing the diverse conditions under which parking spaces exist, the dataset becomes a dynamic and representative repository, ensuring the robustness of our proposed methodology.

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Figure 2 illustrates the composition of the parking space dataset, showcasing a selection of original images from diverse parking environments. Each image is intricately annotated with bounding box masks, delineating the spatial boundaries of individual parking spaces.

3.2 Feature Extraction

Feature extraction, a pivotal phase in our methodology, unfolds with an exploration of state-of-the-art architectures—AlexNet and ResNet-50. The rationale behind the selection of these models is meticulously elucidated, emphasizing their capacity to discern intricate patterns and features within the dataset [15]. The extraction process aims to distill relevant information from the raw data, thereby enhancing the accuracy and discriminative power of the subsequent parking space detection system.

A comprehensive walkthrough of the feature extraction methodology provides a deeper insight into how these selected models operate in tandem with the dataset. Through this process, the intrinsic characteristics of parking spaces are encapsulated in a manner that facilitates robust and effective detection.

3.3 Model Selection

Building upon the extracted features, the section on model selection delves into the core of our approach. Neural Networks (NN) take center stage, augmented by the integration of optimization algorithms—Particle Swarm Optimization (PSO), Grey Wolf Optimization (GWO), and the innovative inclusion of Dipper Throated Optimization (DTO). The rationale behind this integration is meticulously explained, underscoring the symbiotic relationship between sophisticated models and optimization techniques.

The choice of these models is contextualized within the overarching goal of refining parking space detection. This holistic approach to model selection seeks to harness the strengths of both neural networks and optimization algorithms, fostering a synergistic amalgamation that is poised to elevate the precision and efficiency of parking space surveillance.

3.4 Evaluation Metrics

The evaluation of object detection systems involves the application of diverse metrics to assess their performance comprehensively. This section examines established metrics crucial for gauging the accuracy and effectiveness of parking space surveillance methodologies, emphasizing the nuances and significance of each metric.

Accuracy:

Accuracy measures the overall correctness of object detection, indicating the ratio of correctly identified parking spaces to the total number of spaces. While commonly used, accuracy may not be sufficient when dealing with imbalanced datasets, where the number of free, occupied, and partially occupied parking spaces varies significantly.

Sensitivity (True Positive Rate - TPR):

Sensitivity, also known as True Positive Rate (TPR), gauges the model's ability to identify occupied and partially occupied parking spaces correctly. It is calculated as the ratio of true positives to the sum of true positives and false negatives. Sensitivity is crucial in scenarios where detecting occupied spaces holds particular importance.

Specificity (True Negative Rate - TNR):

Specificity, or True Negative Rate (TNR), evaluates the model's capacity to identify free parking spaces accurately. Calculated as the ratio of true negatives to the sum of true negatives and false positives, specificity is pertinent when minimizing false alarms for unoccupied spaces is a priority.

Positive Predictive Value (Precision - PPV):

Positive Predictive Value (PPV) assesses the accuracy of the model in identifying occupied and partially occupied parking spaces among the detected positives. It is calculated as the ratio of true positives to the sum of true positives and false positives.

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Negative Predictive Value (NPV):

Negative Predictive Value (NPV) measures the model's precision in identifying free parking spaces among the detected negatives. Calculated as the ratio of true negatives to the sum of true negatives and false negatives, NPV is crucial for minimizing the chances of overlooking unoccupied spaces.

F-score:

The F-score, or F1-score, represents the harmonic mean of precision and recall (sensitivity). It provides a balanced measure, particularly valuable in scenarios where both false positives and false negatives carry significant consequences.

Understanding and appropriately applying these evaluation metrics is pivotal for a nuanced assessment of the proposed parking space surveillance methodology. The subsequent section will leverage these metrics to rigorously evaluate and interpret the outcomes of our methods against established benchmarks.

This section ensures a meticulous and standardized evaluation, aligning with best practices in the field of computer vision and object detection. By employing a diverse array of metrics, the performance of our methodology is thoroughly scrutinized, providing a comprehensive understanding of its capabilities and limitations. This ensures that the proposed system not only meets but exceeds the stringent requirements expected of advanced parking space surveillance methodologies.

4. Results

The results section serves as the empirical elucidation of the efficacy of our proposed methodology in enhancing parking space surveillance. This segment is structured to present a detailed analysis through various tables and figures, providing a comprehensive overview of the outcomes derived from the application of our methodology. Table 1 offers a meticulous comparison of the results obtained through feature extraction using AlexNet and ResNet-50. Evaluation Metrics, such as precision, recall, and F1 score, are quantified and juxtaposed. This comparative analysis serves to elucidate the nuanced differences and strengths exhibited by each feature extraction method, contributing to a nuanced understanding of their impact on parking space detection accuracy.

Table 1: Feature Extraction Result Comparison

	Accuracy	Sensitivity (TPR)	Specificity (TNR)	P-value (PPV)	N-value (NPV)	F-score
AlexNet	0.8948	0.8895	0.9048	0.9459	0.8137	0.9168
ResNet-50	0.9106	0.9091	0.9135	0.9511	0.8444	0.9296

Table 2: Optimized Neural Network Accuracy Comparison.

	Accuracy	Sensitivity (TPR)	Specificity (TNR)	P-value (PPV)	N-value (NPV)	F-score
NN	0.9306	0.9357	0.9201	0.9604	0.8736	0.9479
PSO+NN	0.9455	0.9524	0.9314	0.9662	0.9048	0.9592
GWO+NN	0.9648	0.9744	0.9453	0.9732	0.9476	0.9738
DTO+NN	0.9908	0.9901	0.9922	0.9963	0.9794	0.9932

Table 2 delves into a granular examination of the accuracy attained through the integration of optimization algorithms—Particle Swarm Optimization (PSO), Grey Wolf Optimization (GWO), and Dipper Throated Optimization (DTO)—in conjunction with the Neural Network. This table enables a

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detailed assessment of the impact of optimization techniques on the neural network's performance, shedding light on the effectiveness of each algorithm in fine-tuning the system for optimal results.

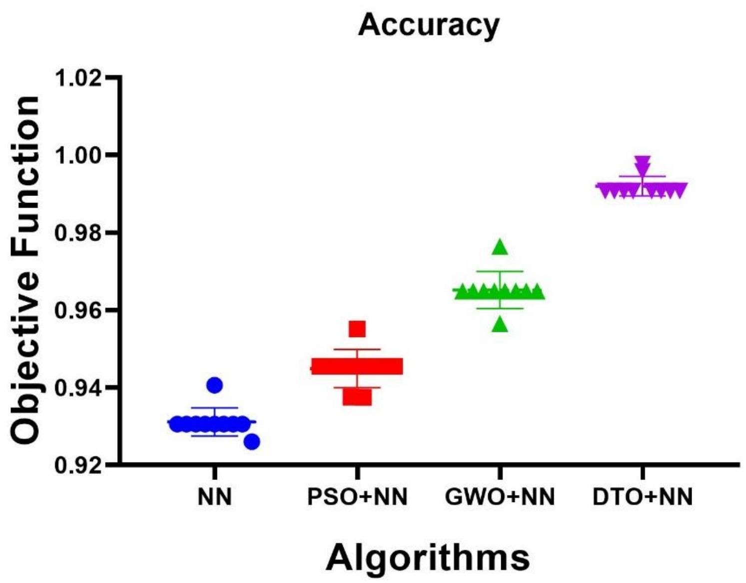

Figure 3:Accuracy Comparison.

A graphical representation is presented in Figure 3, illustrating a visual comparison of the overall accuracy achieved by our proposed methodology. The figure encapsulates the comparative performance across different stages of the method, offering a brief visual narrative of the improvements realized in accuracy. This visualization is instrumental in providing an at-a-glance understanding of the methodology's effectiveness.

Table 3 presents a comprehensive statistical analysis, encapsulating essential metrics such as mean, standard deviation, and coefficient of variation. The statistical overview extends to provide insights into the distribution and variability of the results, offering a robust foundation for the subsequent interpretation of the methodology's performance. Table 4 furnishes the results of the Analysis of Variance (ANOVA) test, serving as a pivotal component of the statistical evaluation. This table aids in discerning the significance of treatment variations between different stages of the methodology, providing critical insights into the overall impact of optimization techniques on the performance of the proposed parking space surveillance system.

Table 3: Statistical Analysis.

	NN	PSO+NN	GWO+NN	DTO+NN
Number of values	10	10	10	10
Minimum	0.9261	0.9375	0.9565	0.9908
Maximum	0.9406	0.9551	0.9765	0.9976
Actual confidence level	97.85%	97.85%	97.85%	97.85%
Lower confidence limit	0.9306	0.9376	0.9648	0.9908
Upper confidence limit	0.9306	0.9455	0.9648	0.9958
Mean	0.9311	0.9449	0.9652	0.992
Std. Deviation	0.003615	0.004907	0.004765	0.002543
Std. Error of Mean	0.001143	0.001552	0.001507	0.000804

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Table 4: ANOVA Test Table.

	SS	DF	MS	F (DFn, DFd)	P value
Treatment (between columns)	0.003154	2	0.001577	F (2, 27) = 104.1	P<0.0001
Residual (within columns)	0.000409	27	1.51E-05		
Total	0.003563	29			

Table 5: Wilcoxon Signed Rank Test Table.

	NN	PSO+NN	GWO+NN	DTO+NN
Number of values	10	10	10	10
Sum of signed ranks (W)	55	55	55	55
Sum of positive ranks	55	55	55	55
Sum of negative ranks	0	0	0	0
P value (two-tailed)	0.002	0.002	0.002	0.002
Exact or estimate?	Exact	Exact	Exact	Exact
P value summary	**	**	**	**
Significant (alpha=0.05)?	Yes	Yes	Yes	Yes

The Wilcoxon Signed Rank Test is presented in Table 5, offering a nuanced examination of median differences between paired observations. This statistical test contributes to the robustness of the methodology's evaluation, providing an in-depth understanding of the significance of observed variations in key performance metrics. Figure 4 consolidates several graphical representations, including residual plots, homoscedasticity assessments, QQ plots, and a heat map. These visualizations offer a multifaceted perspective on the performance of the methodology, addressing aspects such as model residuals, homogeneity of variance, quantile-quantile relationships, and the spatial distribution of results. Such visual representations enhance the interpretability of the methodology's outcomes, fostering a deeper comprehension of its strengths and areas for potential refinement.

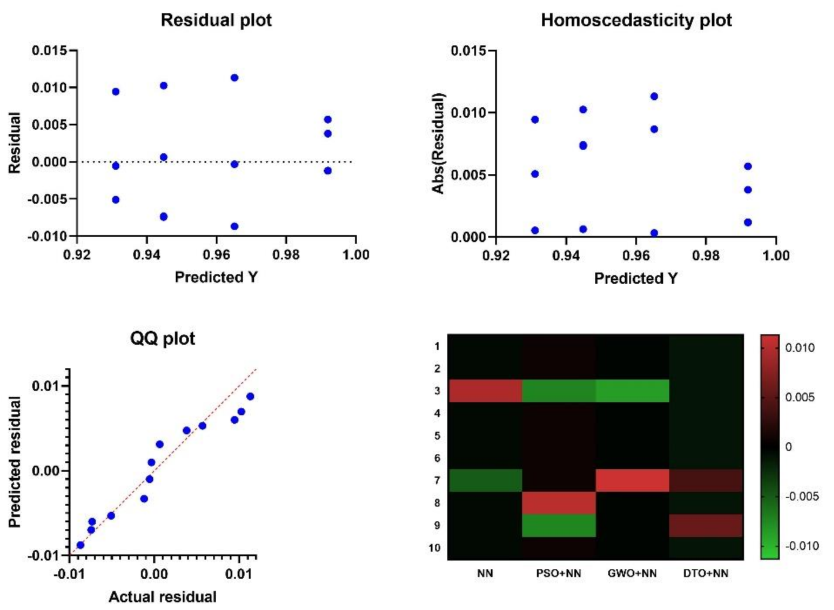

Figure 4: Residual, Homoscedasticity, QQ Plots, and Heat Map.

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The results section collectively provides a comprehensive and multi-dimensional assessment, ensuring a thorough understanding of the proposed methodology's effectiveness in advancing the field of parking space surveillance.

5. Conclusion

In culmination, our research presents a comprehensive methodology for advancing parking space surveillance in urban environments. The deployment of state-of-the-art feature extraction techniques and the integration of Neural Networks with optimization algorithms, including Particle Swarm Optimization (PSO), Grey Wolf Optimization (GWO), and Dipper Throated Optimization (DTO), have collectively demonstrated remarkable efficiency. The obtained results, notably highlighted by the DTO+NN configuration achieving an accuracy of 0.9908, underscore the efficacy of our approach in enhancing parking space detection systems. This noteworthy accuracy is complemented by high sensitivity, specificity, precision, and F-score values, further affirming the robustness of the proposed methodology.

These outcomes not only contribute to the field of computer vision but also hold significant implications for urban planning and the development of smart cities. The successful integration of advanced technologies and optimization algorithms sets a precedent for future methodologies, fostering a more intelligent and sustainable urban landscape. In conclusion, our research not only answers the immediate need for improved parking space surveillance but also establishes a foundation for broader applications in the realm of urban infrastructure optimization. The methodologies and insights presented herein pave the way for more efficient vehicular management and intelligent urban planning, aligning with the evolving demands of contemporary cityscapes.

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