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Smart Parking Management System

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Abstract: *With the fast progression of urbanization, efficient parking management is crucial for high-traffic areas like Los Angeles International Airport (LAX). This research introduces an AI-driven approach to improve smart parking using deep learning and IIoT-based monitoring for real-time analysis. The data from January 2021 to June 2024 includes parking occupancy, vehicle classification, payment behaviors, and violations. Advanced preprocessing techniques, such as Temporal Variability Adjustment and Harmonic Noise Compensation, enhanced data quality, while Proportional Adaptive Balancing and Augmentation (PABA) addressed class imbalance. The Hybrid Adaptive Feature Selector (HAFS) enhanced critical attributes via statistical and genetic diversity techniques. The IncepDenseMobileNet (IDMN) model integrates Inception, DenseNet, and MobileNet architectures to proficiently capture complex patterns via multi-scale feature extraction and efficient depth wise separable convolutions. Simulations show that Unachieved remarkable results, including 98.6% accuracy, 0.95 precision, and 0.96 recall. The model demonstrated a log loss of 0.18 and outstanding performance on new metrics, including Weighted Error Impact Score (WEIS), Dynamic Class Stability Index (DCSI), and Harmonized Classification Risk (HCR), signifying its effectiveness. The examination of the confusion matrix indicated a high predictive accuracy, with AUC values over 97% for both ''Occupancy Status'' and ''Vehicle Type.'' Statistical testing validated the robustness of the technique, while sensitivity analysis identified optimal hyperparameter combinations. The findings indicate significant improvement in parking management via accurate prediction of occupancy trends, identification of peak demand, and detection of payment and violation issues. This paper presents an innovative framework for improving parking operations, dynamic pricing, and resource allocation in urban environments.*

Keywords: Smart parking, IoT, deep learning, data balancing, urban mobility

I. INTRODUCTION

Smart city development presents potential and problems in urban planning, IT infrastructure, and administration. Smart cities improve transportation, energy, public safety, and environmental management via real-time connection and creative services. Globally, urban mobility, especially parking, is a major challenge in smart city development. The rising number of cars in cities has made parking

harder, causing congestion, fuel use, pollution, and driver irritation. Smart cities' sustainability and functioning depend on efficient parking management.

harder, causing congestion, fuel use, pollution, and driver irritation. Smart cities' sustainability and functioning depend on efficient parking management. These issues may be solved by improving parking resource distribution and enabling seamless user experiences using IoT, AI, and advanced communication technologies. IoT is transforming urban issues like traffic and parking. IoT connects devices, sensors, and systems to gather and share data without human interaction. In a smart parking system, sensors can identify parking spot availability and notify a central server, which alerts vehicles via mobile apps. IoT solutions can speed up parking, decrease traffic, and lessen car emissions. Smart parking systems can update and manage parking resources in real time by using Bluetooth, ZigBee, Wi-Fi, and LPWANs to connect devices. Hyper-connected frameworks integrate numerous services to improve their capabilities as IoT evolves.

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Such frameworks orchestrate data analytics across dispersed IoT devices in smart cities, taking into account privacy laws, geographical limits, real-time needs, and quality-of-service characteristics . A more linked IoT ecosystem may combine parking management with traffic monitoring and public transit to provide a full urban mobility solution. Through many-to-many interactions between devices, services, and applications, these frameworks provide increased flexibility and usage of data from numerous sources in varied applications. Parking sensor data may be used for traffic flow research and emergency vehicle guidance, showing IoT's versatility. Smart parking requires multi-sensor systems on roadsides and parking lots for reliable data collecting. These systems employ LiDAR, GPS, and IMUs to collect real-time data on car occupancy, parking place availability, and traffic conditions. Data is sent to cloud servers for processing and analysis, allowing smart parking spot management. Advanced machine learning (ML) and deep learning (DL) have enabled smart parking systems to anticipate parking availability , optimize space distribution, and recognize parking behavior patterns.

Smart parking predictive analytics uses SVMs, random forests, and neural networks. These algorithms can predict future parking demand using previous data and adjust to changing trends in real time. Deep learning methods like CNNs and RNNs can identify parking behavior abnormalities and categorize vehicle kinds based on sensor inputs. Transfer learning has been popular in smart parking because it allows models learned in one city to be used in other locations with minimum reconfiguration. These methods may make smart parking systems more scalable and adaptable to varied urban areas. AI-driven analytics and IoT-enabled smart parking systems may improve urban mobility by offering real-time parking availability updates, improving space use, and minimizing congestion. IoT-based smart parking systems include parking sensors, data communication networks, cloud-based data analytics, and user interfaces. Parking sensors detect cars and record vehicle type, parking time, and ambient variables. Communication networks provide this data to cloud servers, where data analytics algorithms create parking spot management insights. Users may utilize apps to get real-time parking availability and price information that adapts to demand. The development of autonomous IoT-based parking solutions will help reduce urban traffic. These solutions improve parking management and add to urban mobility optimization. Dynamic pricing models, which alter parking prices depending on demand and location, may be combined with smart parking systems to promote uncon- gested parking. Smart solutions reduce car emissions and fuel usage by minimizing parking time, helping smart cities achieve sustainability. Automated parking systems, which employ robotic platforms or car self-parking capabilities, are also growing since they reduce human participation and maximize space.

IoT-based smart parking systems have many benefits, but they also present issues such data privacy, communication protocol management, and system stability under different situations. System design is complicated by real-time data processing and heterogeneous IoT device integration. IoT ecosystems need better standards, data security, and resource management to address these issues. To maximize smart parking technology, devices and systems must be interoperable. Federated learning and edge computing reduce latency and network congestion by spreading computational jobs closer to the data source, improving data processing efficiency and privacy. Smart parking solutions will improve urban living as cities develop. These solutions solve parking management problems and improve transportation infrastructure over time. IoT, AI, and data analytics are projected to develop smart parking, allowing cities to turn parking into a strategic asset for urban planning.

This work creates an IoT-enhanced smart parking manage- ment system that uses deep learning method i.e., Incidence-MobileNet (IDMN) to classify parking events and optimize parking resource utilization. Following are the contribuions of this work:

1) Developed a smart parking management system that is IoT-enabled and employs the IDMN model. This system has achieved an exceptional level of classi- fication accuracy (98.6%) in comparison to existing methods, resulting in more reliable and efficient parking operations.

2) Developed the Hybrid Adaptive Feature Selector (HAFS) by integrating genetic diversity-based and sta- tistical techniques to facilitate more intelligent feature selection. This approach leads to improved prediction accuracy and reduced computational complexity in smart parking applications.

3) Introduced the Proportional Adaptive Balancing and Augmentation (PABA) technique, which effectively addresses data imbalance by generating synthetic samples for underrepresented classes and pruning redundant instances, resulting in enhanced model fairness and performance.
4) Enhanced predictive modeling capabilities and pro- vided deeper insights into parking patterns by imple- menting the Attribute Synthesis and Transformation (AST) framework to engineer sophisticated features such as the Temporal Usage Index (TUI) and Violation Likelihood Factor (VLF).
5) Developed innovative performance metrics (WEIS, DCSI, and HCR) that are tailored to smart parking scenarios. This enables a more thorough evaluation that prioritizes severe errors, ensures class stability, and balances risk in predictions.
6) Provided practical suggestions for real-world smart parking management, such as optimizing space
The article is organized as follows: In Section II, the most important literature to this work is looked at. This gives background and draws attention to similar studies. In Section III, the proposed approach model is shown, along with a description of the research's structure and methods. The modeling results are shown in Section IV, along with a full explanation of the results. Finally, Section V has the closing comments, which are a summary of the study's main results and consequences.

II. RELATED WORK

Recent research on smart parking systems has shown innovative urban parking management approaches, technol- ogy, and tactics. IoT, AI, and machine learning developed effective smart parking solutions. This section discusses this research's methods, accomplishments, and limits using relevant literature.

Smart parking management may benefit from commu- nication, sensor, and AI-based IoT systems. An approach uses machine vision, deep learning, and CNNs to detect available parking places. CNNs allowed more accurate image-based algorithms than sensor-based ones. In a real- world deployment, camera quality and weather hindered solution performance. A proposed deep learning-based vehicle filtering system estimates parking lot traffic flow using MobileNet. MobileNet is suitable for real-time applications because its lightweight architecture improves parking space detection accuracy while reducing processing. Large parking spots required extensive data processing, which the system struggled with.

An alternative technique predicts parking place availability using deep contrastive networks and spatial transform algorithms. Model architecture addressed vehicle size, displacement, and spatial distortions, resulting in more accurate predictions than typical techniques. The device functioned well but had scaling issues in high-volume parking lots. ResNet-based deep learning was used to categorize parking places in images as occupied or free in a self-parking system. The model's residual connections improved parking condition detection by allowing deeper learning without performance degradation. Low light lowered slot recognition accuracy.

Parking availability was predicted using an ensemble learning method, including decision tree models and bagging techniques. The ensemble strategy employing Random Forest achieved 94% accuracy on the Birmingham parking dataset by pooling model outputs to reduce variation. Historical data may not accurately reflect current con- ditions, limiting projections. The SFpark initiative used real-time demand data to enhance parking space usage with dynamic pricing. They combined IoT data with logistic regression, and SVM improved parking space allocation, search times, and emissions. Unpredictable peak-hour pricing frustrated users, hindering system adoption.

Amsterdam's smart parking system monitors parking place use using sensors and cameras using DenseNet architecture. DenseNet improved real-time updates by optimizing dense network feature propagation. Real-time updates failed in weak network areas. The proposed smart parking system employs K-Nearest Neighbors (KNN) and SVM classifiers for real-time parking place suggestions within a 2-km radius via wireless communication. Drivers can quickly find parking with two-minute updates. Although effective, the necessity for constant internet con- nectivity was a challenge, especially in locations with poor Wi-Fi. The London smart parking policy employs ANPR and Transformer-based models to monitor and enforce parking availability. The attention mechanism in Transformer architecture allowed the

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model to manage enormous license plate photo datasets and offer real-time parking data. Extended vehicle identification prompted privacy concerns. LSTM networks are used in a real-time parking management system with cloud connection and ultrasonic sensors to pre- dict occupancy trends. LSTM improves time-dependent parking availability prediction. The deployment cost of numerous sensors was a considerable challenge, particularly in large cities.

In recent years, there has been a noticeable shift toward the use of advanced modeling techniques aimed at improving traffic forecasting, vehicle behavior analysis, and the overall efficiency of urban transportation systems. One notable approach in this space is the fusion of visual and quantified traffic features to address heterogeneous flow conditions, as demonstrated in where multimodal inputs enhance the model's ability to interpret dynamic traffic environments. Building on this foundation, the work in introduces a Dynamic Trend Fusion Module that captures shifting temporal patterns to deliver more responsive and accurate short-term predictions. Another promising direction comes from which proposes a Bilinear Spatiotemporal Fusion Network that jointly models' space and time relationships to boost predictive performance in city traffic management. From a perception standpoint, the study in focuses on LiDAR-based scene flow estimation and object segmentation—an essential step for real-time navigation in autonomous driving. On the behavioral modeling front, explores how drivers' previewing behaviors can inform short-term lateral movement predictions, while empha- sizes trajectory forecasting based on personalized driving styles and anticipated lane changes. In the context of smart logistics, puts forward a hybrid model that blends fuzzy logic with convolutional factorization machines, offering improved accuracy in delivery time estimation.

Machine learning classifiers, including Random Forest, Decision Trees, and Gradient Boosting Machines (GBM), were employed to predict parking occupancy, with Random Forest achieving the highest accuracy of 91.73% .

Aggregating model predictions improved classification per- formance despite hyperparameter tuning sensitivity. Research on the impact of Transport Infrastructure Connectivity (TIC) on conflict resolution uses natural experiments and deep learning models like LSTM and BiLSTM to analyze time-series data. Results indicated that models could capture sequential infrastructure-related events but failed to generalize across urban contexts. Singapore's unified parking platform, using a Vision Transformer (ViT), pro- vides real-time parking information from various IoT and camera-based devices. ViT's ability to include global context in photographs increased parking space estimations, but parking system data consistency was still a problem. Intelligent automotive navigation systems employ RL to optimize autonomous parking trajectory, demonstrating its adaptability to dynamic conditions. However, sensor accuracy influenced system performance and real-world decisions. Research on vision-based traffic comprehension techniques identified the use of YOLO for object identification in parking management systems. YOLO archi- tecture allowed real-time vehicle detection. However, smaller objects or obscured cars in busy parking lots hampered accuracy. In recent years, intelligent transportation systems have seen a notable shift toward the use of attention-driven and transformer-based deep learning models to tackle the complexities of urban mobility and parking management. For example, DenseNet-121 integrated with the Swin Transformer has been successfully applied to detect vacant parking spaces, offering improved spatial awareness and object recognition in dense city environments. Similarly, EfficientNet has shown promise in classifying parking occupancy across large-scale datasets, achieving strong accuracy while maintaining a lightweight computational footprint. Comparative research has also emphasized the advantages of Vision Transformers (ViT) over traditional CNNs, particularly in their ability to understand broader con- textual relationships within traffic and mobility scenes. In another line of work, lightweight transformer architectures have been implemented in vehicle detection systems for smart parking, striking a useful balance between detection precision and deployment efficiency at the edge level. Collectively, these studies highlight the growing role of transformer-based models in advancing the capabilities of smart urban infrastructure. The summarized view of literature is shown in Table 1.

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Ref	Methods Applied	Outcomes Achieved	Challenges Noted
[12], [15], [33]	CNNs, ResNet, YOLO, Computer Vision	Improved parking space detection accuracy using image-based methods and object detection, enhancing real-time management capabilities.	Dependent on camera quality, lighting conditions, and object occlusion in crowded areas.
[13], [18]	MobileNet, DenseNet	Achieved efficient real-time parking monitoring with lightweight architectures suitable for large-scale applications.	Faced scalability issues and network coverage limitations in extensive parking areas.
[14], [20], [31]	Transformers, ANPR, Vision Transformer	Monitored parking availability with attention mechanisms, handling large datasets and providing global context for parking management.	Challenges with data consistency and privacy concerns due to extensive use of vehicle identification data.
[16], [29]	Random Forest, Ensemble Learning	High accuracy in predicting parking occupancy through ensemble methods, leveraging bagging techniques for improved performance.	Sensitive to hyperparameter tuning and reliance on historical data for predictions.
[17], [32]	Reinforcement Learning, Dynamic Pricing	Optimized parking allocation and trajectory planning using demand-based approaches, reducing emissions and improving traffic flow.	User dissatisfaction due to price variability and sensitivity to sensor accuracy in dynamic environments.
[19], [21]	KNN, LSTM, SVM	Predicted parking trends and provided real-time recommendations, capturing temporal dependencies for better occupancy forecasting.	High deployment costs and requirements for constant internet connectivity.
[30]	LSTM, BiLSTM, Time-Series Analysis	Analyzed temporal patterns in parking data, assessing the impact of intelligent transportation control measures.	Limitations in generalizing across diverse urban contexts.

TABLE 1. Literature review summary.

A. RESEARCH GAPS

The examined literature shows IoT, machine learning, and deep learning advancements in smart parking systems. Still, many research gaps exist. Conventional parking space recog- nition methods, including Convolutional Neural Networks (CNNs) and MobileNet, might be hindered by environmental variables like camera quality and weather condition, This suggests the need for more robust models that can manage environmental changes without losing accuracy. Scalability remains an issue, especially in big parking lots with substantial data processing. For instance, deep con- trastive networks like ResNet face computational challenges in high-volume regions. Few efficient designs can sustain low latency for real-time applications across deployment sizes. Current parking availability prediction algorithms often depend on historical data, which might hinder adaptation to real-time changes. Random Forest and ensemble learning work well with structured datasets but struggle to adapt to parking demand changes. More dynamic and adaptable algorithms are required for real-time prediction accuracy. Technologies like Automatic Number Plate Recognition (ANPR) and Vision Transformers (ViT) for parking monitoring present privacy issues These considerations emphasize the need for privacy-preserving methods that maintain user anonymity while providing high-quality services. In cities with many sensors and platforms, data consistency and interoperability issues arise across parking systems. High deployment and maintenance costs for sensor-based solutions, such as LSTM networks or reinforcement learning, are a major obstacle. Cost-effective parking management methods that limit infrastructure use and provide accurate and trustworthy results are needed.

B. PROBLEM STATEMENT

Given the research limitations, smart parking systems do not match the demands of dynamic and varied urban landscapes. Existing techniques suffer from scalability issues, environmental variables like illumination and weather, and depend on past data that may not adequately represent current parking situations. Image-based monitoring systems face privacy problems and data inconsistencies among platforms, limiting their mainstream use. To address these challenges, a more adaptive and robust IoT-enhanced smart parking management system that uses advanced deep learning techniques like ResNet and Trans- former architectures to improve classification accuracy and urban resource utilization is needed. The suggested parking system should react to real-time situations, decrease deploy- ment costs, and maintain user privacy without sacrificing service quality. This research integrates advanced machine learning models with IoT infrastructure to create a scalable, real-time, and privacy-preserving smart parking management solution for urban parking spaces.

III. PROPOSED SYSTEM MODEL

The proposed framework improves smart parking man- agement at LAX by integrating advanced methodolo- gies. Temporal Variability Adjustment (TVA), Dynamic Range Segmentation (DRS), Harmonic Noise Compensation (HNC), and Categorical Embedding Extension (CEE) are used to handle temporal patterns, sensor fluctuations, environmental noise, and categorical data representation. The Proportional Adaptive Balancing and Augmentation (PABA) approach provides synthetic samples for underrepresented classes using Density-Weighted Synthetic Augmentation

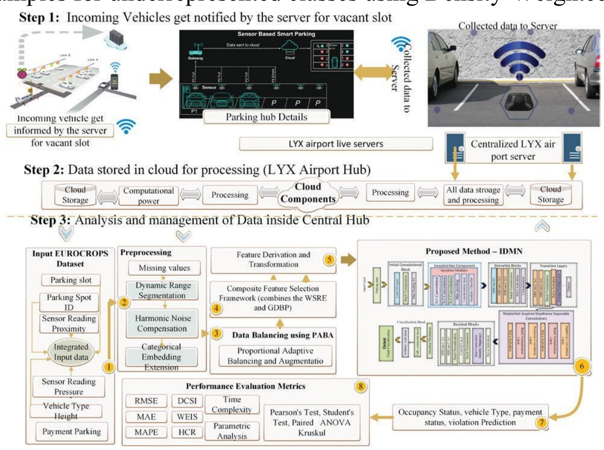

FIGURE 1. Proposed parking management framework with IDMN.

(DWSA) and removes majority class redundancy using Cluster-Oriented Pruning Strategy. HAFS uses Weighted Statistical Relevance Evaluation (WSRE) and Genetic Diversity-Based Pruning (GDBP) to maintain statistically important and diverse characteristics. Using Attribute Syn- thesis and Transformation (AST), feature engineering creates new attributes like Temporal Usage Index (TUI), Normalized Acoustic Impact Score (NAIS), and Violation Likelihood Factor (VLF) to capture complicated data patterns. Incep- DenseMobileNet (IDMN) improves classification accuracy by integrating Inception, DenseNet, and MobileNet designs for multi-scale feature extraction, dense aggregation, fast depthwise separable convolutions, and residual attention refinement. To evaluate the model's robustness and adaptabil- ity in real-world parking scenarios, traditional metrics and novel measures like WEIS, DCSI, and HCR are used. The proposed system framework is shown in Figure 1.

A. DATASET DESCRIPTION

This study is based on a publicly accessible dataset titled the ‘‘Smart Parking Management Dataset’’, covering the period from January 2021 to June 2024. It con- tains comprehensive information on parking occupancy trends, vehicle classifications, payment records, and viola- tions. The dataset is archived with a DOI for long-term accessibility and reproducibility, and can be accessed at: https://doi.org/10.34740/KAGGLE/DSV/9686139. The data from one of the nation's busiest airports provides important insights on parking occupancy, car classification, payment practices, and possible parking violations over three and a half years. The data tracks daily parking activity changes according to airline schedules, seasonal travel peaks, and traffic conditions. The dataset captures the intricacies of airport parking management by documenting over 1,000 occurrences of LAX parking facility operations. IIoT technology in the parking infrastructure enabled dataset collecting. These systems collected sensor readings and environmental monitoring to classify and analyze parking incidents. The dataset is a significant source of information for improving smart parking management and classification algorithms to optimize airport parking operations. The data may be used to evaluate intelligent parking solutions in high-traffic metropolitan areas in different situations.

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B. PREPROCESSING OF DATA

The dataset preparation includes feature scaling, smoothing, variability treatment, and categorical data representation. The approaches are adapted to the LAX parking dataset. The first preprocessing method, Temporal Variability Adjustment (TVA), handles data with uneven temporal patterns. It weights timestamps by parking activity, giving greater occupancy periods more weight. The correction factor, γv, is determined

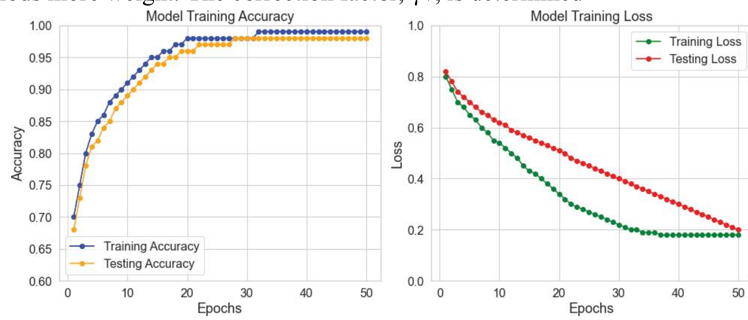

FIGURE 18. Model training accuracy vs loss.

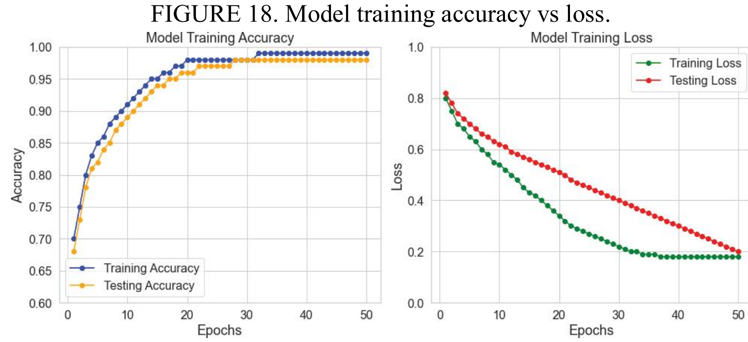

FIGURE 19. Sensitivity analysis of IDMN.

shows how hyperparameters impact model performance, helping practitioners choose the best settings for real-world categorization.

V. CONCLUSION

This research uses advanced ML and IoT data analysis to improve smart parking management. The study tackles parking management issues, including occupancy forecast, payment compliance, and infraction detection, by merging IDMN with LAX IoT data. The framework's 98.6% accuracy and performance in WEIS, DCSI, and HCR make it better than CNN, MobileNet, and RF. The novel combination of TVA, PABA for data balance, and HAFS shows how robust preprocessing and feature selection improve classification results. AST also allowed the generation of innovative characteristics such as TUI and VLF, improving data representation and prediction accuracy. ANOVA and Pearson Correlation show that the ResNet-Transformer performs well in many metrics, proving its durability. Confusion matrices, correlation analysis, and sensitivity assessments help build dynamic pricing, space distribution, and automated enforcement tactics by studying parking habits. This research enhances smart parking technology and opens up urban transportation possibilities. The suggested technology is adaptable and scalable across varied contexts, making it useful for smart city applications. This research allows data- driven, intelligent parking management systems to boost operational efficiency, income, and user experience.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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