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Exploring Parking Occupancy Prediction Models: Analyzing Patterns for enhanced Urban Planning

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Abstract:

Urban parking systems have long been an integral part of city infrastructure, evolving over time to accommodate growing urban populations and increasing vehicle ownership. Traditional parking management systems relied on static signage, manual enforcement, and limited data collection, making it difficult to efficiently allocate parking resources. With the rise of smart technologies, the parking industry has gradually shifted towards automated systems and digital solutions. Traditional urban parking systems typically involve the allocation of parking spaces based on fixed zones or manual entry. These systems often require drivers to search for available parking, leading to traffic congestion, wasted fuel, and unnecessary emissions. Furthermore, manual enforcement of parking rules leads to inefficiencies in managing parking space usage and improper parking practices. Current systems fail to provide real-time parking information, often leading to inefficient utilization of available spaces and longer search times for drivers. This results in increased fuel consumption, environmental pollution, and a frustrating experience for city residents. With urban areas growing rapidly, it is essential to adopt more intelligent and efficient systems to improve parking management. The integration of Machine Learning (ML) in parking systems offers an opportunity to enhance the user experience, optimize parking space allocation, reduce traffic congestion, and minimize environmental impacts. The proposed system integrates machine learning algorithms with real-time data. By utilizing historical data and traffic patterns, the system will allocate parking spaces efficiently, reduce search times, and dynamically adjust parking fees based on demand, leading to improved urban parking efficiency.

Keywords: Minimize Congestion, Manage occupancy dynamically, improved parking efficiency, reduce search times.

1. INTRODUCTION

Urban parking has become a significant challenge in rapidly vehicles, with 30 million passenger vehicles, yet urban parking infrastructure has not kept pace. Traditional parking systems, including street parking and open-air lots, which are overcrowded and inefficient, exacerbating traffic and environmental issues. The primary problem with these systems is the lack of real-time information about parking availability, causing drivers to waste time searching for spaces, contributing to further congestion and pollution.

Fixed parking fees, along with limited enforcement, have led to underutilized spaces and illegal parking.

The integration of machine learning (ML) in parking systems offers a promising solution by using real-time data from sensors and cameras to predict parking space availability and optimize parking management. ML-based systems can dynamically adjust pricing based on demand, reducing congestion and improving space utilization. This technology also provides valuable data that can aid in urban planning and help create more efficient parking infrastructures. The need for such systems is increasingly critical in cities like Delhi, Mumbai, and Bangalore, where rising vehicle ownership is overwhelming existing parking capacities. Real-time, data-driven solutions can reduce search time, lower emissions, and enhance the overall urban driving experience, making smart parking systems a crucial element of sustainable urban mobility.

Key applications of ML-based parking systems include real-time availability updates, dynamic pricing to balance demand, traffic congestion reduction, and improved sustainability by reducing fuel consumption and emissions. These systems also provide valuable data for urban planning, can be integrated with other smart city infrastructure, and support electric vehicles by identifying EV charging stations.

2. LITERATURE SURVEY

Yang presented a comprehensive survey on parking services in smart cities, examining various technologies and systems designed to optimize parking availability, enhance user experience, and reduce congestion.

Zheng focused on parking availability prediction for sensor-enabled car parks in smart cities, proposing an intelligent approach for forecasting parking space availability using data from various sensors. Their work aimed to improve the efficiency of parking management systems, contributing to better urban mobility.

Caicedo explored the real-time prediction of parking space availability, introducing a predictive model that incorporates historical data to forecast parking space usage in urban areas.

Channamallu conducted a comprehensive study on parking occupancy prediction, analyzing different methodologies and models used for predicting parking space occupancy.

Kotbre viewed smart parking guidance, monitoring, and reservation systems, examining the latest trends in smart parking technology and their integration into intelligent transportation systems.

Pamidimukkala analysed the barriers to adopting electric vehicles in Texas, identifying key obstacles related to infrastructure, policy, and consumer behavior. The study aimed to inform policy recommendations and strategies to promote electric vehicle adoption.

Huang explored location-based services, highlighting ongoing research and evolution in the field. Their paper discussed the impact of location based technologies on urban planning and transportation systems, with a focus on improving service delivery through geospatial data.

Sester focused on mobility data analysis, particularly in the context of mobile mapping systems. Their research emphasized the role of mobility data in enhancing transportation planning and management, offering insights into the potential of mobile mapping for improving urban mobility.

Channamalluconducted a comparative analysis of parking occupancy prediction models, evaluating the performance of different approaches in predicting parking space availability.

Liu explored parking occupancy prediction using gradient boosting decision trees, proposing a machine learning model to predict parking space usage.

Sun applied decision trees and random forests for short-term parking occupancy prediction, comparing the performance of different models and providing valuable insights into their practical applications in parking management.

Patel conducted an exploratory analysis of temporal and spatial patterns of autonomous vehicle collisions, examining factors influencing autonomous vehicle accidents and the implications for future transportation systems.

Hendricks and Out water proposed a demand forecasting model for park-and-ride lots, focusing on predicting parking demand at transit stations. Their study aimed to optimize parking lot utilization and reduce congestion at park-and-ride facilities.

INRIX Research highlighted the economic impact of parking-related issues in the United States, estimating that searching for parking costs Americans billions of dollars annually.

Caicedo explored parking management and modeling car park patron behavior, focusing on underground parking facilities.

Shoup examined the issue of "cruising for parking," discussing the impact of circling for parking on traffic congestion and urban mobility. His work highlighted the need for efficient parking management strategies to mitigate congestion caused by parking searches.

Channamallu reviewed smart parking systems, summarizing the latest advancements in parking management technologies. Their work explored the integration of sensors, data analytics, and intelligent systems for optimizing parking in urban areas.

Linsurveyed smart parking solutions, discussing various technological advancements and strategies used to enhance parking efficiency in urban environments. Their paper emphasized the role of intelligent transportation systems in managing parking availability.

The Virginia Metro Rail Authority conducted a feasibility study on real time parking information at metro rail stations, exploring the potential benefits of providing real-time parking availability data to commuters. Their study aimed to improve the parking experience for metro rail users.

Adepu explored construction cost overruns during COVID-19, analyzingthe impact of the pandemic on construction projects and identifying key factors contributing to cost increases. Their research provided insights into the

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challenges faced by the construction industry during the pandemicreported on the introduction of high-tech parking meters in San Francisco, discussing the benefits of modernized parking meter systems and their impact on parking management.

Richtel highlighted the role of mobile apps in parking, discussing how smart phones and location-based services have revolutionized the way drivers find and pay for parking.

Liu explored parking occupancy prediction using gradient boosting decision trees, proposing a machine learning model to predict parking space usage.

3. PROPOSED METHODOLOGY

CatBoost (Categorical Boosting) is an advanced gradient boosting algorithm developed by Yandex. It is specifically designed to handle categorical features efficiently, making it well-suited for datasets with many categorical variables. CatBoost is built on top of the gradient boosting framework, which combines multiple weak learners (usually decision trees) to create a strong model.

How it Works:
Gradient Boosting: CatBoost builds decision trees sequentially, where each tree corrects the errors of the previous one. The model minimizes a loss function (log-loss for classification) by adjusting the weights of each tree.
Categorical Handling: CatBoost has unique feature of processing category data. It converts category features into numerical values efficiently using ordered target statistics, which prevents over fitting and improves model accuracy.

Symmetric Trees: Unlike traditional gradient boosting algorithms, Cat Boost builds symmetric trees, which are more efficient in terms of memory and computation.

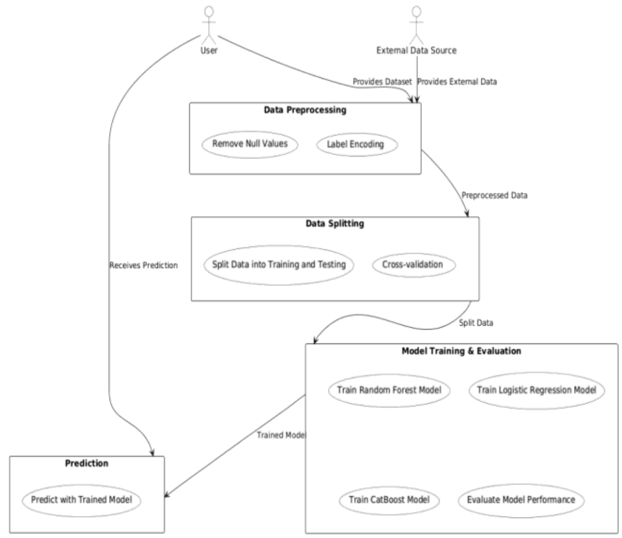

Figure 1: Block diagram.

The proposed methodology typically includes the following steps:

Dataset Pre processing:
After uploading the dataset, the next step is data pr process, which is crucial to prepare data for machine learning models. The first task is to handle missing or null values.

Data Splitting:
Once the dataset is pre processed, the next step is splitting the data into training and testing subsets. This is a standard procedure to evaluate how a model generalize to unseen data. Typically, data is divided into : a training set (usually 70-80% of the data) and a test set (typically 20-30%).

Performance Comparison:
After training both the existing models and the proposed model ,the next step is to compare their performance. This comparison is done using various evaluation metrics such as accuracy, precision, recall, F1-score, and AUC.
Prediction of Output from Test Data with Trained Model:Once the best-performing model has been identified, the final step involves predicting the output using the trained model on the test data.

Architecture:

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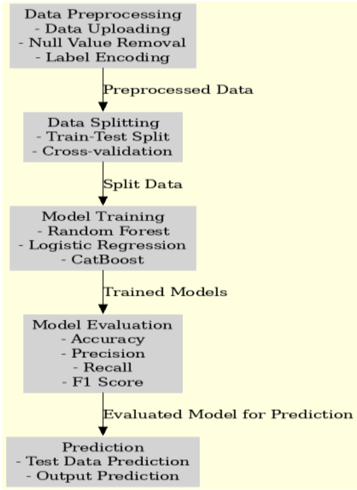

Input: A set of features X = [x_1, x_2, ..., x_n]

Weights: Each feature is assigned a weight w=[w1,w2,.wn].

Sigmoid Function: The weighted sum of features is passed through the sigmoid function to output a probability.

Prediction: The predicted class is based on the probability threshold.

Applications:

Real-time Prediction: One of the key areas for future development is integrating real-time data from parking sensors, cameras, and IoT devices to predict parking violations instantly. This could allow for automated ticketing and reduce the need for manual intervention, making enforcement more efficient and effective.

Integration with Smart City Infrastructure: As cities evolve into "smart cities," integrating this system with other urban services (e.g., traffic management, public transportation, or city planning tools) could offer a holistic approach to urban mobility and law enforcement.

Model Optimization: Further improvements can be made by optimizing the current machine learning models, including hyper parameter tuning, feature engineering, and exploring other algorithms like XG Boost, Light GBM, or deep learning-based models to handle larger datasets with more complex features.

Advantages:

It is commonly used in many problems. Some of their advantages are mentioned here:

Improved User Experience: Enhances convenience and satisfaction for users by providing intuitive interfaces, faster services, and personalized options.

Reduced Traffic Congestion: Implements solutions that set traffic flow, minimize delays, and optimize routes, easing urban mobility and commute times.Enhanced Safety: Introduces measures like real-time monitoring, automation, and predictive analytics to reduce accidents and improve overall public safety.Scalability and Flexibility: Enables systems to grow and adapt to increasing demand, while easily adjusting to different use cases and environments.

4. EXPERIMENTAL ANALYSIS

Figure 1 displays the primary interface where users can navigate to various features of the system. The home page typically includes a welcome message, options to register or log in, a brief description of the system's functionality, and links to different sections like the parking violation prediction model, performance metrics, and user support.

Figure 1: Home Page

Figure 2 showcases the registration page used for both users and administrators. It includes fields for entering personal information, such as username, password, email, and role selection (User or Admin). The form is designed to ensure that both types of users can register easily. The user interface includes input validation and submission options, providing a secure registration process.

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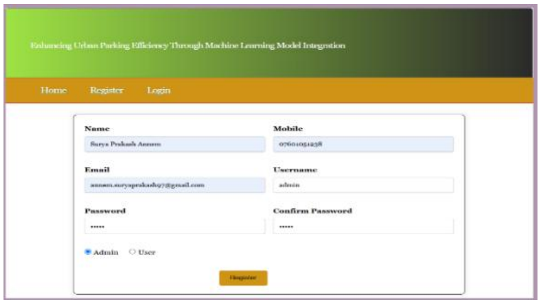


Figure 2: Registration

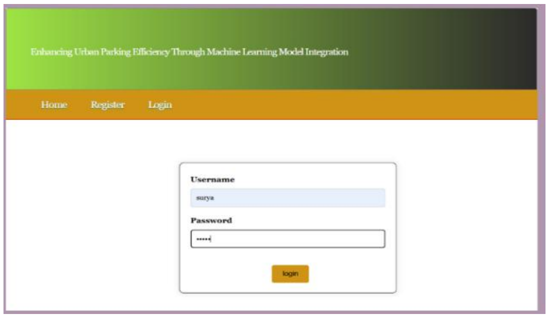


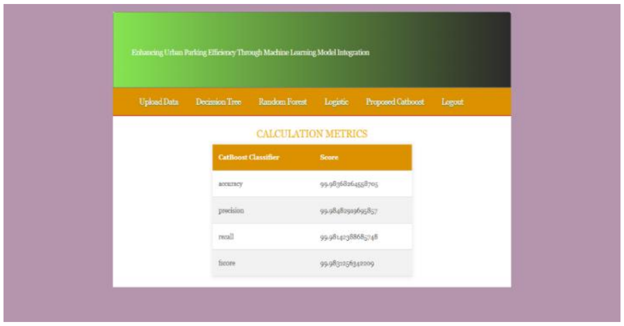
Figure 3: User Login Page

Figure 3 displays the login page for users to access the parking violation detection system. It includes fields for entering the registered username and password. There may also be a "Forgot Password" option for recovery and a "Sign Up" link for new users. Upon successful login, users are redirected to the dashboard, where they can upload parking violation datasets and perform other operations.

	Plate ID	Registration State	Plate Type	Violation Code	Vehicle Body Type	Vehicle Make	Issuing Agency	Street Code1	Street Code2	Street Code3
0	51526.0	43.0	32.0	10.0	55.0	171.0	11.0	64151.0	15635.0	49295.
1	115980.0	43.0	32.0	10.0	60.0	171.0	11.0	64151.0	15635.0	49295.
2	89416.0	43.0	32.0	10.0	60.0	11.0	11.0	64151.0	65617.0	15635.

Figure 4: Sample parking dataset

Figure 4illustrates the uploaded dataset for parking violations. The dataset consists of various columns related to parking violations, such as vehicle plate ID, registration state, violation code, vehicle make, and violation time. The table showcases a few sample records of the dataset, which will be processed to train the prediction model and provide insights regarding parking violations.



CatBoost Classifier	Score
accuracy	99.98368264558705
precision	99.98482919695857
recall	99.98142388685748
fscore	99.98312563412009

Figure 5: Performance Metrics of the Proposed Cat Boost Model

Figure 5showcases the performance metrics of the CatBoost model, which is the proposed enhancement for the parking violation detection system. It includes the same performance indicators (accuracy, precision, recall, F1-score) but with the improved performance achieved by CatBoost. This figure serves as evidence of the effectiveness of the CatBoost model in comparison to the existing models.

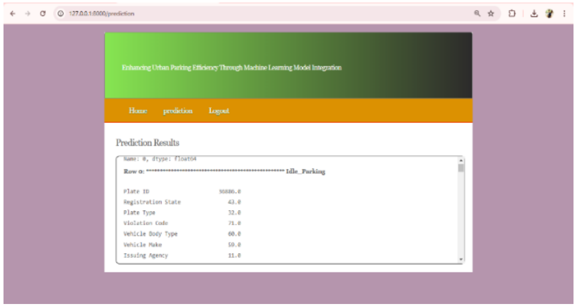


Figure 6: Proposed Model Prediction on User Uploaded Test Data

Figure 6 demonstrates the predictions made by the proposed model (CatBoost) on a user-uploaded test dataset. It displays the predicted violation status or outcomes based on the input data, helping the user understand how well the model performs in real-world scenarios. It could also include a graphical representation of the predictions (e.g., bar charts or tables) and possibly a comparison with the actual values to visualize accuracy.

5. CONCLUSION

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This research focuses on using machine learning algorithms, specifically Random Forest, Logistic Regression, and CatBoost, to predict urban parking violations. The study demonstrates how advanced machine learning techniques can improve traffic management and parking enforcement by providing accurate predictions. CatBoost outperformed traditional models in terms of prediction accuracy, particularly due to its ability to handle complex datasets with categorical features, requiring less manual tuning.

The project highlights the importance of data quality and model selection in achieving reliable predictions. By comparing various algorithms, it was found that CatBoost offered superior performance in predicting parking violations, making it a valuable tool for law enforcement and city planners to enhance decision-making and reduce human error in traffic management.

Looking ahead, the project proposes several future developments, such as real-time prediction using IoT data, integration with smart city infrastructure, and further optimization of models. Additionally, the system could be expanded to inform urban planning, improve scalability, and integrate advanced data sources for more accurate predictions, all while helping to reduce parking violations through increased public awareness and compliance.

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