Mobile Application for Identifying Anomalous Behavior and Conducting Time Series Analysis Using Heterogeneous Data

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Abstract. Understanding anomalous behavior and spatial changes in an urban parking area can enhance decision-making and situational awareness insights for sustainable urban parking management. Decision-making relies on data that comes in overwhelming velocity and volume, that one cannot comprehend without some layer of analysis and visualization. This work presents a mobile application that performs time series analysis and anomaly detection on parking lot data for decision-making. The mobile application allows users to add pins in the parking lot and analyze the pin data over a period of time. Our approach uses parking pins to identify each vehicle and then collect specific data, such as temporal variables like latitude, longitude, time, date, and text (information from the license plate), as well as images and videos shot at the location. Users have the option of placing pins at the location where their car is parked, and the information collected can be used for time series analysis. By examining the data pattern, we may quickly identify vehicles parked in restricted spaces but without authorization and vehicles parked in disabled spaces but owned by regular users. This time series analysis enables the extraction of meaningful insights, making it useful in the identification of recurring patterns in parking lot occupancy over time. This information aids in predicting future demands, enabling parking administrators to allocate resources efficiently during peak hours and optimize space usage. It can be used in detecting irregularities in parking patterns, aiding in the prompt identification of unauthorized or abnormal parking and parking violations which includes parking of the wrong type of vehicle, and parking at restricted or reserved areas.

Keywords: Heterogeneous Data · Time Series Analysis · Anomalous Behavior · Object Detection · Data Visualization

1 Introduction

Efficient urban parking management is a crucial component of urban planning and transportation management, particularly in densely populated urban areas as it directly impacts traffic flow, congestion, and environmental sustainability. With the continuous growth of vehicle numbers and limited parking spaces, optimizing the utilization of

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available parking resources has become imperative. To effectively manage parking areas, decision-makers require accurate and timely insights into parking behavior and patterns. However, this objective is often challenged by anomalous behaviors that occur in parking lots, such as unauthorized parking, violations of parking regulations, and irregular occupancy patterns. To address this issue, this paper introduces a mobile application that leverages time series analysis and anomaly detection techniques to identify anomalous behavior and conduct comprehensive analysis using heterogeneous data collected from parking lots.

The mobile app harnesses the power of time series analysis to analyze diverse data sources, including location information, timestamps, and license plate details. By collecting and analyzing this data, the app provides parking administrators with valuable insights into parking patterns and enables real-time detection of anomalies. It consists of two modules: The Information Gathering Module and the Time Series Analysis Module. The Information Gathering Module allows users to conveniently add pins to mark specific parking areas of interest as shown in Fig. 1. These pins capture diverse data, including temporal variables such as latitude, longitude, time, date, and textual information derived from license plates. Additionally, users can capture images and videos at the parking location, providing additional context for analysis as shown in Fig. 2. The Time Series Analysis Module is a powerful tool that enables users to analyze the accumulated pins over a defined period. By applying time series analysis techniques to the collected data, meaningful patterns and trends in parking behavior can be extracted. This analysis facilitates the identification of recurring patterns in parking lot occupancy over time, aiding in predicting future demands and optimizing resource allocation during peak hours. It also enables parking administrators to optimize space usage and enhance overall management efficiency. The mobile application's capabilities extend beyond identifying recurring patterns. It also plays a crucial role in detecting anomalous parking behaviors and violations. By examining the data patterns, the application can quickly identify vehicles parked in restricted spaces without authorization and those occupying disabled spaces despite belonging to regular users. This functionality helps maintain parking regulations, prevent unauthorized parking, and ensure fair and efficient utilization of parking spaces.

The real-time anomaly detection capability of the mobile app is of great significance as it allows for prompt action and response. Instances of unauthorized parking can be rapidly detected, enabling parking administrators to take appropriate measures such as issuing warnings or imposing penalties. Similarly, violations of parking regulations, such as parking in restricted areas or exceeding time limits, can be promptly identified, ensuring compliance, and maintaining order within parking lots. The benefits of the mobile application extend to decision-makers in urban parking management. By providing comprehensive insights into parking behavior and facilitating data-driven decision-making, the application enhances situational awareness and enables proactive resource allocation. Decision-makers can make informed choices regarding parking regulations, optimize parking space usage, and effectively address parking violations, ultimately contributing to more sustainable and efficient urban parking management. The utilization of time series analysis techniques in the mobile app offers several advantages. Trend identification facilitates the prediction of future parking demands, enabling parking administrators to allocate resources effectively. Occupancy pattern detection helps identify irregular parking behaviors, such as vehicles exceeding designated time limits or displaying inconsistent parking patterns. These insights contribute to proactive decision-making and more efficient resource allocation, ultimately leading to improved space utilization and reduced congestion in parking lots.

Fig. 1. Time series analysis showing pins captured over parking lot.

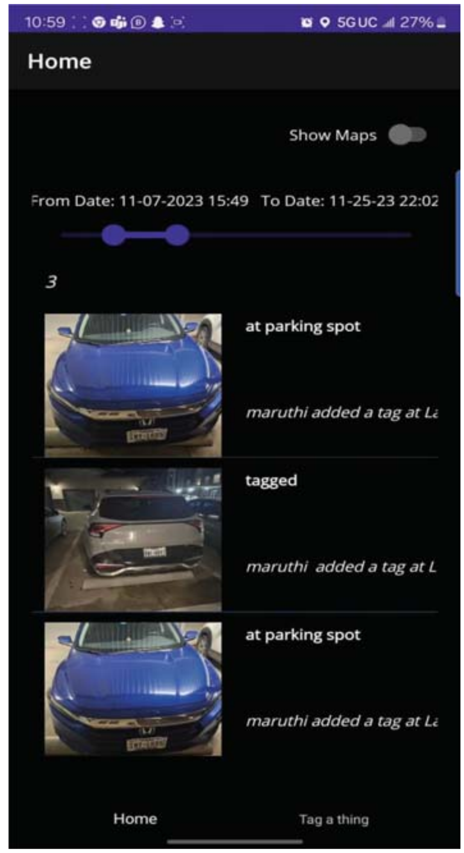

Fig. 2. Parked vehicle at parking lot

The mobile application can provide real-time information on available parking spaces. By integrating with parking infrastructure such as sensors or surveillance systems, the app can collect data on occupancy levels in parking lots in real-time. This data is then processed and made available to users through the app. Users can access the app to check the availability of parking spaces in specific areas or parking lots. The app can display the number of available spaces, indicate whether a parking lot is full or nearing capacity, and provide real-time updates as spaces become available or occupied. The real-time information on available parking spaces helps drivers plan their parking more efficiently, saving time and reducing frustration. It also contributes to better space utilization by directing drivers to parking lots with available spaces, minimizing the search for parking, and reducing traffic congestion in urban areas. Additionally, parking administrators can use the real-time occupancy data to monitor and manage parking lots more effectively. The effectiveness and accuracy of the proposed mobile application and time series analysis techniques have been validated through real-world experiments conducted on diverse parking lot datasets. The results demonstrate the app's ability to detect anomalous behavior with high precision, providing parking administrators with reliable information to make informed decisions and take appropriate actions. Time series analysis using heterogeneous data is needed in many applications such as smart homes, autonomous cars, and aviation. Data analysis of a time series data set is challenging due to data mining complexity. Gers [1] et al. have explored heterogeneous time series, using neural networks.

This research aims to advance the field of parking lot management by offering a comprehensive solution to the challenges posed by anomalous behavior. The data-driven approach of the mobile app, combined with its real-time analysis capabilities, contributes to more efficient and proactive parking management strategies. By optimizing space utilization, improving traffic flow, and enhancing the overall urban experience, the mobile app has the potential to revolutionize parking management in urban areas, benefiting both residents and visitors by improving urban mobility. This paper introduces a mobile application that leverages time series analysis and anomaly detection techniques to enhance decision-making and situational awareness in urban parking management. By utilizing heterogeneous data and providing comprehensive insights into parking behavior, the application empowers decision-makers to optimize resource allocation, predict future demands, and detect anomalous parking behaviors. The subsequent sections of this paper will delve into the technical details of the mobile application's architecture, data analysis techniques, and the results obtained through its implementation.

2 Related Work

Gwo-Jiun et. al. [2] have used cellular automata as a recommendation mechanism for smart parking in vehicular environments. They have developed SPARK: Smart Parking Management System that incorporates remote parking monitoring, automated guidance, and parking reservation mechanism. SPARK provided real-time parking navigation, smart theft protection, and parking information. O'Donovan et al. [3] have proposed a system to monitor cars in a parking lot to inform the user of free parking spaces and their location. They have used wireless sensor network system in parking areas to gather this information. Whereas, Jin et al. [4] have focused on security issues in a parking lot for identifying the user's car. On the other hand, Hanzl [5] has proposed a parking information guidance systems application used in urban areas and multistory car parks. Shin et.al [6] have introduced a smart parking guidance system by developing intelligent parking guidance algorithm. Geng et al. [7] have developed and conducted pilot studies for smart parking guidance system.

Sharma et al. [8–10] have developed a mobile augmented reality (AR) system for emergency response, which provided real-time information and instructions during emergencies. These studies highlight the use of mobile applications for data collection, analysis, and enhancing emergency response in various contexts. Augmented reality (AR) applications have been developed for object detection, safety using parking data [11]. Caliskan et al. [12] have built a parking guide system based on vehicular ad hoc networks (VANETs) that uses a continuous-time homogeneous Markov model for parking availability prediction. Prediction of parking space availability in real time is challenging problem that has been presented by Caicedo et al. [13]. They have introduced an intelligent parking reservation (IPR) system, which lets users provide real-time parking information using their parking preferences.

Smart phones have been used to detect empty parking spaces. Lan et al. [14] have proposed an intelligent driver location system for smart parking using smart phones where the relevant parking space can be detected when the driver parks or leaves the parking space. Performance analysis of proximity and light sensors for smart parking has also been examined [15]. Atif et al. [16] have used a cloud-based architecture and internet of things (IoT) approach to bring together parking space service providers and drivers. The use of IoT devices in car parking has also brought security issues. Chatzigiannakis et al. [17] have emphasized a privacy-preserving smart parking system using an IoT elliptic curve based security platform. They have demonstrated elliptical encryption methods to be more efficient as compared to other encryption methods. Smart services of parking structures have been also examined for smart parking solutions in urban areas [18].

3 Heterogeneous Data and System Architecture

The mobile application for identifying anomalous behavior and conducting time series analysis relies on the utilization of heterogeneous data from various sources. This diverse dataset provides a comprehensive understanding of parking behavior and facilitates accurate anomaly detection. The application collects and integrates the following types of data:

1. Temporal Data:
   Temporal data plays a crucial role in analyzing parking behavior over time. By examining temporal patterns, the application can identify recurring behaviors, such as daily or weekly parking routines, and detect deviations from the norm. This information is valuable for understanding parking demand patterns, identifying irregularities or anomalies in behavior, and predicting future parking trends. It can also help optimize resource allocation by aligning parking supply with demand during specific time periods. In the application, a feature that tracks and analyzes parking behavior over time is implemented. The pins which user has marked in home section helps in identifying recurring patterns and anomalies in parking routines and provide predictive analytics to forecast future parking trends based on temporal data. This ultimately optimizes resource allocation by aligning parking supply with demand during specific time periods.
2. Geographical Data:
   Geographical data provides spatial context to the analysis of parking behavior. By integrating geographical information, such as the location of parking areas and the surrounding environment, the application can identify spatial patterns, parking hotspots, and areas with high parking demand. This enables urban planners and parking administrators to make informed decisions about parking infrastructure development, pricing strategies, and enforcement efforts. Geographical data also supports the identification of parking patterns based on proximity to popular destinations, transportation hubs, or events. The geographical data displays parking locations on a map within the application. It also provides information about the parking spots within 100 meters'

range, and it enables users to search for parking based on location and proximity to their destination.

3. Sensor Data:
Sensor data, such as information from parking occupancy sensors or smart meters, offers real-time insights into parking availability and utilization. By integrating sensor data into the application, it can provide up-to-date information on parking occupancy levels, detect anomalies or unusual parking events in real-time, and optimize parking operations. This data allows for efficient management of parking resources, improved enforcement actions, and enhanced user experience by providing accurate information on available parking spaces. Application integrates real-time sensor data from parking using the camera of the device and GPS location. This sensor data helps to display current parking availability and occupancy levels in real-time. In future it can send notifications or alerts to users when parking spaces become available or when anomalies are detected. Hence sensor data is used to optimize parking operations and resource management.
4. Textual Data:
Textual data derived from license plates or other sources can provide additional context and insights into parking behavior. By analyzing textual data, the application can identify specific vehicles, track repeat offenders, and detect parking violations. This information is valuable for enforcement purposes, enabling targeted actions against violators and improved compliance with parking regulations. Textual data also facilitates the identification of abnormal or unauthorized parking instances and supports evidence-based decision-making. In the Time Series analysis and Anomalies detection application, a system is implemented to analyze and process textual data that user has implemented. In future it can detect parking violations and track repeat offenders. The textual data provides evidence-based decision-making for enforcement actions. This application enables users to save the information which includes user details, car information which they have entered and helps to report parking issues by submitting textual information.
5. Multimedia Data:
The application's ability to capture images and videos at parking locations allows for visual documentation and verification of parking behavior. Multimedia data can be used to verify parking violations, assess parking space occupancy visually, and gather evidence for enforcement actions. This visual context enhances the accuracy of anomaly detection and provides transparency in the enforcement process. It also supports user engagement by allowing users to report parking issues through visual evidence. The application allows users to capture and upload images or videos of car when parked. The multimedia data helps to visually verify parking behavior and occupancy. This enhances anomaly detection and provide transparency in the enforcement process and supports user engagement by enabling visual evidence submission for parking-related concerns with the data in database.
6. External Data Sources:
Integration with external data sources, such as weather conditions, events, or public transportation schedules, further enhances the analysis of parking behavior. For example, considering weather data helps identify weather-induced changes in parking demand, such as increased parking activity during pleasant weather. Incorporating

event data allows the application to detect anomalies associated with large gatherings or special occasions, enabling proactive management strategies to address heightened parking demand during such events. Integration with public transportation schedules can provide insights into parking patterns influenced by transit usage and help optimize multimodal transportation planning. The application incorporates event data to detect anomalies associated with large gatherings or special occasions and it can use public transportation schedules to understand parking patterns influenced by transit usage and optimize transportation planning.

By leveraging the diverse nature of heterogeneous data, the mobile application can provide a comprehensive understanding of parking behavior, detect anomalies, and facilitate evidence-based decision-making. The combination of various data types allows for a more nuanced analysis, leading to improved parking management, enhanced user experience, and sustainable urban development.

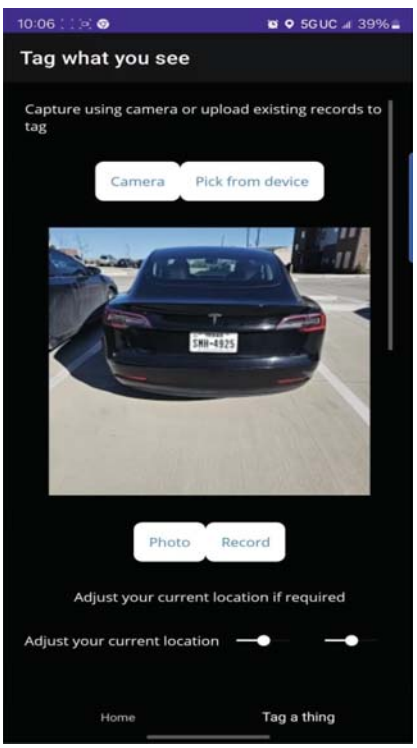

Fig. 3. Time series analysis showing pins captured over parking lot.

Fig. 4. Tag section where information of the image is captured.

The mobile application for identifying anomalous behavior and conducting time series analysis using heterogeneous data utilizes a robust and scalable system architecture. The architecture is designed to handle the collection, integration, processing, and analysis of diverse data types from heterogeneous sources. The key components of the system architecture:

- Data Collection Layer:

  The data collection layer is responsible for gathering data from various sources. It includes modules or components that interact with different data providers, such as parking occupancy sensors, smart meters, external APIs (Application Programming Interfaces), user input, and multimedia capture functionalities as shown in Fig 3. The data collection layer ensures the acquisition of different types of heterogeneous data needed for the analysis.

- Data Integration Layer:

  The data integration layer is responsible for consolidating and harmonizing the heterogeneous data collected from different sources. It includes data pre-processing modules that transform and standardize the data to ensure compatibility and consistency. This layer may also involve data cleansing and data quality verification processes to address any inconsistencies, errors, or missing values in the data.
- Data Storage Layer:

  The data storage layer is responsible for storing the integrated and processed data captured in Fig 4. It may employ a combination of databases, data lakes, or data warehouses to accommodate the diverse data types and support efficient data retrieval and querying. The storage layer ensures the availability and scalability of the data for analysis and future reference.
- Analytics and Processing Layer:

  The analytics and processing layer encompasses the core functionalities of the mobile application. It includes modules for conducting time series analysis, anomaly detection, and predictive modeling. This layer applies advanced algorithms and techniques to the heterogeneous data to uncover patterns, detect anomalies, and generate actionable insights. It may involve statistical analysis, machine learning, or data mining techniques tailored to the specific requirements of the application.
- Visualization and User Interface Layer:

  The visualization and user interface layer focus on presenting the analysis results and providing an intuitive user experience. It includes components for generating interactive visualizations, charts, and reports to communicate the findings effectively. The user interface layer enables users to interact with the application, input data, configure analysis parameters, and access the results. It may also provide real-time notifications, alerts, or recommendations based on the analysis outcomes.
- Integration with External Systems:

  The mobile application may require integration with external systems or APIs to access additional data sources or services. For example, it may integrate with weather APIs to retrieve real-time weather data or with event management systems to obtain information on scheduled events. These integrations enhance the contextual analysis and provide a more comprehensive understanding of parking behavior.
- Security and Privacy:

  The system architecture incorporates robust security measures to protect the privacy and integrity of the data. It includes authentication mechanisms, secure data transmission protocols, and access control mechanisms to ensure that only authorized individuals can access sensitive information. Privacy considerations are considered during data collection, storage, and handling to comply with applicable privacy regulations and protect user data.
- Scalability and Performance:

  The system architecture is designed to handle large volumes of data and support scalability. It leverages technologies such as distributed processing frameworks, parallel computing, or cloud-based infrastructure to efficiently process and analyze the heterogeneous data. This ensures that the application can handle increasing data loads and accommodate future growth in user base and data sources without compromising performance.

- Real-time Processing:

  To provide timely insights and enable real-time anomaly detection, the system architecture incorporates real-time data processing capabilities. It includes components that can ingest and process streaming data from sensors or other real-time sources. Real-time processing allows for immediate detection and response to anomalous behavior, enabling proactive management strategies and timely notifications to users.
- Data Governance and Metadata Management:

  The system architecture incorporates data governance principles and metadata management practices. It includes mechanisms for data cataloging, data lineage tracking, and data lifecycle management. This ensures that data can be traced back to its source, and metadata about the data, such as its origin, quality, and transformations applied, is captured, and maintained. Data governance and metadata management support data integrity, compliance, and facilitate reproducibility of analysis results.
- Model Training and Re-training:

  If the mobile application utilizes machine learning or predictive modeling techniques, the system architecture includes components for model training and re-training. It may involve a separate module for model development and training using historical data. Periodic re-training of models allows them to adapt to changing patterns and behaviors, ensuring the application's accuracy and effectiveness over time.
- API Management:

  The system architecture includes an API management layer to expose functionalities and data to external systems or third-party developers. It provides secure and controlled access to the application's capabilities through well-defined APIs. API management enables integration with external systems, data exchange with partners, or the development of third-party applications that can leverage the mobile application's functionalities.
- Data Privacy and Compliance:

  The system architecture incorporates privacy and compliance measures to safeguard user data and ensure compliance with relevant regulations, such as data protection laws. It includes mechanisms for data anonymization, encryption, and access control to protect sensitive information. The architecture also supports audit trails and logging to track data access and usage for compliance and security purposes.
- Continuous Monitoring and Alerting:

  To ensure the reliability and availability of the application, the system architecture includes components for continuous monitoring and alerting. It may involve monitoring the performance of the application, data quality, and system health. Real-time alerts and notifications are generated when anomalies or issues are detected, allowing for prompt resolution, and minimizing downtime.
- Integration with External Tools and Services:

  The system architecture allows for seamless integration with external tools and services that complement the mobile application's functionalities. For example, it may integrate with data visualization tools, statistical analysis software, or cloud-based storage services. These integrations enhance the application's capabilities, expand its functionality, and leverage existing tools and services in the ecosystem.

4 Time Series Analysis Implementation

This mobile application leverages a multi-layered architecture to provide a seamless experience for exploring locations and capturing associated images as shown in Fig. 5. The Key components includes user interface, google maps api, camera, file storage.

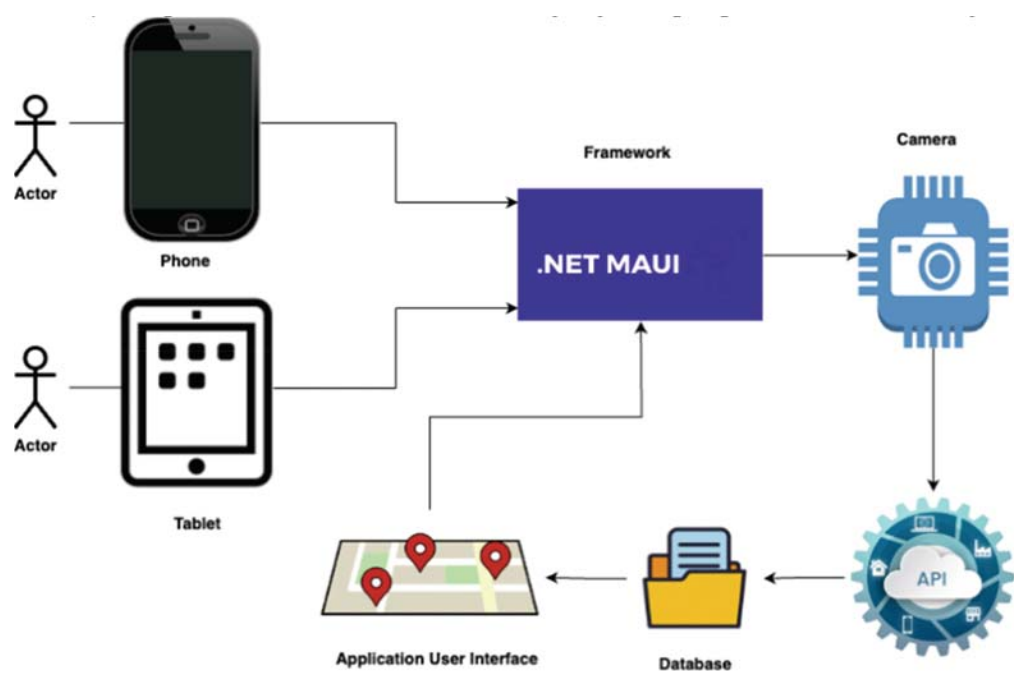

Fig. 5. Interacting with the map through Oculus touch controllers.

User interacts with the application's UI on a phone or tablet. The application is built with.NET MAUI for cross-platform development using C# and XAML. It handles UI interactions, location services, and data management. Google Maps API provides map data, geocoding, and location functionalities. Local database store's location pins, associated information, and user-captured images securely and the device camera is used for capturing images at specific locations..NET MAUI enables efficient cross-platform development with a single codebase for Android, iOS, and other platforms and C# facilitates development and XAML allows for visually appealing UI design. The application provides a user-friendly interface with essential elements like a map displaying location pins, buttons for interaction, and image displays. The application utilizes a dedicated data access layer (e.g., Entity Framework Core) to interact with the local database, providing abstraction and data management logic. Offline functionality is also achieved by caching map data and pins locally. When online, synchronization with cloud storage or other data sources ensures consistency. Images are stored as references to external files or embedded within the database, considering storage efficiency and performance trade-offs. Compression techniques might be used to optimize image size. The application caches map data and relevant location pins while online, allowing basic functionality even without internet connectivity. Updates can be downloaded and applied when online. Real-time Updates (if applicable): Integration with real-time data sources like traffic APIs could enable dynamic updates on the map, enhancing user experience. The architecture is modular and adaptable to accommodate future growth, new features, or changing requirements. Offline data management, image storage limitations, and security concerns can also be addressed with appropriate techniques and architectural decisions implemented in the application.

Table 1. Framework Characteristics Summary

Characteristics	Framework
Engine	.NET MAUI
Programming Language	C#
Decision-Making System	✓
Dynamic agents	✓
Intension support	✓

As mentioned previously the application was implemented in.NET MAUI. It is integrated with location services API which helps to get the google coordinates of the location. Table 1 summarizes the characteristics of our framework.

5 Anomaly Detection and Time Series Analysis

5.1 Anomaly Detection

The anomaly detection functionality of the application plays a crucial role in identifying irregularities and abnormal parking behavior. It utilizes advanced anomaly detection algorithms to analyze the collected time series data and detect deviations from expected patterns. These algorithms can identify outliers, anomalies, and unusual trends in the parking data. By leveraging anomaly detection, the application can promptly flag instances of unauthorized or abnormal parking. For example, it can detect vehicles parked in restricted areas without proper authorization, vehicles occupying disabled parking spaces without the necessary permits, or vehicles parked for extended periods in time-limited zones. This helps parking administrators to take immediate action and enforce parking regulations effectively. The anomaly detection algorithm in the mobile application is designed to handle different types of parking violations by leveraging various techniques and data features. Here's how it can address different parking violations:

1. Unauthorized Parking in Restricted Areas:

The algorithm utilizes location data, such as latitude and longitude, to determine if a vehicle is parked in a restricted area. It compares the parked vehicle's location with predefined boundaries or zones that indicate restricted areas. If the vehicle is detected within a restricted zone without proper authorization, the algorithm flags it as an anomaly.

2. Occupying Disabled Parking Spaces without Authorization:

To identify vehicles occupying disabled parking spaces without the necessary permits, the algorithm incorporates additional data such as information from the license plate. It compares the license plate information with a database of authorized permits and disabled parking registrations. If a vehicle is found to be parked in a disabled space without valid authorization, it is flagged as an anomaly.

3. Time-Limited Parking Violations:

The algorithm considers time-related variables, such as date and time of parking, to detect violations related to time-limited parking zones. It compares the duration of parking against the specified time limits for a particular area. If a vehicle exceeds the allowed time limit, it is identified as an anomaly, indicating a time-limited parking violation.

4. Parking in Reserved or Designated Areas:

The algorithm utilizes predefined data or user-inputted information regarding reserved or designated parking areas. It checks if a vehicle is parked in an area that is designated for specific users, such as employees, residents, or permit holders. If a vehicle is found in a reserved area without the appropriate authorization, it is flagged as an anomaly.

5. Wrong Vehicle Type Parking:

The algorithm can consider additional data sources, such as vehicle registration information and user-provided details, to identify parking violations related to the wrong type of vehicle. For example, it can detect if a motorcycle is parked in a space designated for cars or if a commercial vehicle is parked in a residential area where it is prohibited. If a vehicle is parked in a space that is incompatible with its type, it is marked as an anomaly.

5.2 Time Series Analysis

The time series analysis module of the application is designed to extract meaningful insights from the collected parking data over a specific period. It enables administrators to understand the occupancy patterns and trends in the parking lot over time. Through time series analysis, the application can identify recurring patterns in parking lot occupancy, such as peak hours or days with high parking demand. This information is vital for predicting future parking demands and optimizing the allocation of parking resources. By accurately forecasting parking needs, administrators can ensure that sufficient parking spaces are available during peak periods, reducing congestion and improving overall parking efficiency. Additionally, time series analysis allows administrators to track changes in parking behavior and identify long-term trends. For example, it can reveal shifts in parking preferences or changes in the utilization of specific parking areas. This insight enables administrators to make informed decisions regarding the allocation of parking spaces, adjustments to parking regulations, or the implementation of new parking strategies. The time series analysis module can indeed help in evaluating the impact of policy changes in parking management. By analyzing the historical parking data before and after the implementation of policy changes, administrators can assess the effectiveness and consequences of those changes. Here's how the time series analysis module can assist in evaluating policy impact:

1. Comparative Analysis: The module allows administrators to compare the parking occupancy patterns and trends before and after the policy changes. By examining the time series data, they can identify any significant shifts in parking behavior, such as changes in occupancy rates, parking durations, or utilization of specific parking areas. This comparative analysis helps assess the direct impact of the policy changes on parking dynamics.
2. Identification of Changes in Demand: Time series analysis can reveal changes in parking demand resulting from policy changes. For example, if a new parking regulation is implemented that restricts parking in a particular area, the module can track the occupancy levels in that area over time. By comparing the occupancy patterns pre- and post-policy change, administrators can determine whether the policy has effectively influenced the parking behavior and demand in the intended manner.
3. Forecasting Accuracy: The time series analysis module can evaluate the accuracy of forecasting models in predicting parking demand after policy changes. By comparing the predicted demand based on historical data with the actual observed demand after policy implementation, administrators can assess the effectiveness of their forecasting methods. This evaluation provides insights into the reliability of the forecasts and helps refine the forecasting models for future policy evaluations.
4. Impact on Congestion and Efficiency: Policy changes often aim to reduce parking congestion and improve overall parking efficiency. The time series analysis module can assess whether the implemented policies have achieved these goals. By analyzing occupancy patterns and trends, administrators can measure the changes in parking availability, utilization rates, or the average time taken to find parking spaces. This evaluation helps determine whether the policy changes have resulted in reduced congestion and improved parking efficiency.
5. Iterative Policy Refinement: The insights derived from the time series analysis can guide administrators in refining and fine-tuning parking policies. By understanding the impact of previous policy changes, administrators can make informed decisions about further adjustments or modifications to better align with the desired outcomes. The module provides a feedback loop that supports an iterative approach to policy refinement based on data-driven insights.

By combining anomaly detection with time series analysis, the application offers a comprehensive approach to parking management. Anomaly detection helps identify and address parking violations and irregularities, while time series analysis provides insights into occupancy patterns, trends, and forecasting. These functionalities assist administrators in effectively managing parking resources, enforcing regulations, and enhancing the overall parking experience for users.

6 Conclusions

The development of a mobile application incorporating time series analysis and anomaly detection for urban parking management offers significant benefits for decision-making and situational awareness. The application addresses the challenges posed by the overwhelming velocity and volume of parking data by providing analysis and visualization capabilities. By utilizing the information gathering module, users can add pins to parking lots, capturing essential data such as location, time, date, license plate information, images, and videos. The time series analysis module then analyzes the collected data, enabling the identification of recurring patterns in parking lot occupancy and the detection of anomalies or irregularities. The application's ability to identify unauthorized parking in restricted spaces or violations such as parking in disabled areas without authorization enhances decision-making and supports prompt action by parking administrators. Furthermore, the analysis of parking patterns aids in predicting future demands and optimizing resource allocation during peak hours, contributing to efficient space utilization, and improved operational efficiency.

The application's ability to perform time series analysis on parking data provides parking managers with valuable insights for informed decision-making. By analyzing historical occupancy patterns, administrators can make data-driven decisions regarding pricing strategies, resource allocation, and infrastructure planning. This promotes more efficient and effective parking management practices. Understanding parking occupancy patterns through time series analysis enables parking managers to allocate resources more efficiently. By identifying peak hours and high-demand areas, administrators can adjust staffing levels, implement dynamic pricing schemes, or even introduce shuttle services to optimize resource utilization and improve customer satisfaction. The application's analysis of parking patterns helps identify underutilized or over utilized parking spaces. This knowledge allows parking administrators to optimize space utilization by reallocating resources or implementing strategies such as shared parking arrangements or dynamic space allocation systems. Maximizing space utilization can alleviate parking congestion and reduce the need for additional parking infrastructure. Anomaly detection capabilities enable the application to identify unauthorized parking, parking violations, and abnormal occupancy patterns in real-time. Prompt identification of such issues allows for proactive interventions, such as issuing fines, sending alerts to parking enforcement personnel, or implementing automated enforcement systems. This promotes compliance with parking regulations and contributes to improved safety and security in parking areas.

The insights gained from time series analysis can inform long-term planning and expansion efforts. By understanding parking demand trends, administrators can plan for future infrastructure development, identify areas for potential expansion, or implement new parking facilities in locations with high projected demand. This data-driven approach ensures that parking systems are designed to meet the needs of growing urban areas. By leveraging time series analysis insights, parking managers can enhance the overall user experience for parkers. This can include providing real-time parking availability information through mobile apps or digital signage, offering personalized parking recommendations based on historical data, or implementing seamless payment systems to streamline the parking experience. Effective parking management contributes to environmental sustainability by reducing traffic congestion and associated emissions. By optimizing parking resource allocation and providing real-time information on parking availability, the application helps minimize unnecessary circling and search for parking, leading to reduced traffic congestion and lower carbon emissions. Overall, the mobile application's integration of time series analysis and anomaly detection empowers parking managers with valuable insights for sustainable urban parking management. By leveraging data-driven decision-making, administrators can enhance situational awareness, optimize resource allocation, and improve the overall effectiveness and efficiency of urban parking systems.

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