Time Series Analysis for Detecting Anomalous Behavior Using a Mobile Device

Maruthi Prasanna Chellatore[1], Rishitha Reddy Pesaladinne[1], and Sharad Sharma[2](✉)

[1] Department of Computer Science, University of North Texas, Denton, TX, USA
{maruthiprasannachellatore,rishithareddypesaladinne}@my.unt.edu
[2] Department of Information Science, University of North Texas, Denton, TX, USA
sharad.sharma@unt.edu

Abstract. Detecting anomalous behavior in real-time for an urban area from large data is a challenging problem. Efficient parking management in urban areas is crucial for optimizing space utilization, improving traffic flow, and enhancing the overall urban experience. This paper presents a comprehensive study on the application of time series analysis techniques for detecting anomalous behavior in urban parking lots. It proposes a mobile application that allows users to collect data on location, time, and license plate details. The collected data is then analyzed using advanced time series analysis methods to identify anomalous behavior, such as unauthorized parking, irregular occupancy patterns, and violations of parking regulations. Real-world experiments on diverse parking lot datasets demonstrate the high accuracy of the proposed approach in detecting anomalies. These insights are valuable for predicting future parking demands, enabling parking administrators to efficiently allocate resources during peak hours and optimize space utilization. Additionally, the analysis can detect irregularities in parking patterns, promptly identifying unauthorized or abnormal parking and violations, such as parking the wrong type of vehicle or parking in restricted or reserved areas. This work advances the state-of-the-art in time series analysis for parking lot management, providing valuable insights for practitioners and researchers in the field. It also contributes to more efficient, data-driven, and proactive parking management strategies, leading to improved urban mobility and enhanced user satisfaction.

Keywords: Anomalous behavior detection · time series analysis · urban parking lots · mobile application · parking management · resource optimization · parking enforcement · machine learning · urban mobility · user satisfaction

1 Introduction

Urban areas face significant challenges in managing parking spaces effectively. As cities grow, the demand for parking increases, leading to congestion, inefficient resource allocation, and unauthorized or abnormal parking behavior. To address these issues, it is crucial to have a comprehensive understanding of parking patterns and the ability to detect anomalies in real-time. This research recognizes the importance of leveraging

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data analysis and visualization techniques to enhance decision-making and situational awareness in urban parking management.

Urban parking management faces numerous challenges, including limited parking space, inefficient resource allocation, unauthorized and abnormal parking, parking violations, lack of real-time data, traffic congestion, and the need to balance the diverse needs of stakeholders. These challenges require innovative solutions that leverage data-driven decision-making, advanced technologies, and effective enforcement strategies to optimize parking utilization, improve traffic flow, and enhance the overall parking experience in urban areas. The problem addressed in this research is the overwhelming volume and velocity of parking lot data, which poses challenges for decision-makers to extract meaningful insights. Traditional methods of manual data analysis are time-consuming and impractical, given the scale and complexity of the data. There is a need for an automated and efficient solution that can handle heterogeneous data sources, such as temporal variables, license plate information, images, and videos, to identify anomalous behavior and patterns in parking lot occupancy.

This paper describes the development of a mobile application that addresses the challenges in urban parking management by leveraging time series analysis and anomaly detection techniques. The mobile application aims to provide decision-makers with a user-friendly interface to gather parking lot information, analyze the collected data over time, and identify anomalous behavior. By leveraging these techniques, the mobile application enhances the overall effectiveness and efficiency of parking management, resulting in better traffic flow, reduced congestion, and enhanced user experience. By achieving this objective, the research aims to enhance decision-making capabilities, predict future parking demands, optimize resource allocation, and detect parking violations promptly. Mobile applications have been developed for various purposes, including urban parking behavior analysis [1, 2], anomaly detection [3, 4], navigation [5], emergency response [6, 7], and building evacuation [8, 9].

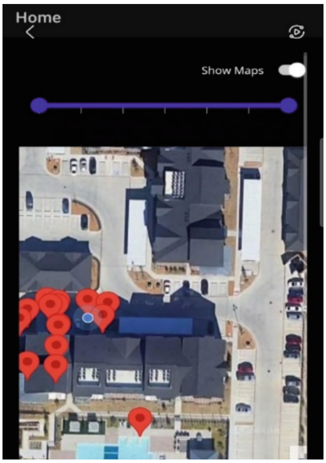

Fig. 1. View of pins for time series analysis.

Figure 1 shows the view of collected data through the use of geo location pins. Each pin can store data in multiple formats such as image, video, text, time and geo-location. The user can add multiple pins through the use of mobile device at specific locations. These pins help in conducting time series analysis to understand parking patterns and usage trends over the period of time.

The rest of the paper is organized as follows: Sect. 2 discusses studies related to the one reported in this paper; Sect. 3 details the information gathering and time series analysis module. It also describes the data collection through user interaction in the mobile device; Sect. 4 describes the system framework and implementation of the mobile application; Sect. 5 discusses the results and analysis of the mobile application; Sect. 6 concludes this paper and gives ideas for future work regarding this study.

2 Related Work

Li et al. [3] proposed an urban parking behavior analysis using mobile sensing data. They utilized mobile devices to collect data and analyze parking behavior patterns. Wang et al. [10] focused on urban parking anomaly detection using machine learning algorithms in a mobile application context. They explored the use of machine learning techniques to detect abnormal parking behavior. Sharma et al. [6, 8, 11] 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, navigation, and building evacuation. Sharma and Engel [7] developed a mobile AR system for object detection, alert, and safety. Their system utilized AR technology to detect objects in the environment and provide real-time alerts and safety instructions. Sharma et al. [6–8] and Stigall et al. [9, 12] evaluated mobile AR applications for building evacuation. They explored the use of AR technology, including intelligent signs and HoloLens devices, to enhance evacuation procedures and provide real-time guidance. These studies highlight the application of AR technology in various contexts, such as object detection, safety, and building evacuation.

Time series analysis plays a crucial role in understanding patterns and detecting anomalies in various domains. Tong et al. [13] proposed an anomaly detection method in urban parking behavior based on time series analysis. They applied time series analysis techniques to parking data to identify abnormal patterns. Liu and Han [14] focused on anomaly detection in large-scale parking data using probabilistic topic modeling. They utilized time series analysis and probabilistic models to identify unusual parking behavior. These studies demonstrate the application of time series analysis in detecting anomalies in parking behavior through mobile applications.

There has been an increasing interest in the field of mobile applications, time series analysis mobile applications, and augmented reality applications. For example, Mannuru et al. [5] developed a mobile AR application for navigation and emergency response. They have utilized AR technology to provide real-time navigation instructions and enhance situational awareness during emergencies. Spatio-temporal analysis and deep learning have also been used for data mining in parking behavior analysis [15–17]. Sharma et al. [18–21] developed an emergency response application using HoloLens for building evacuation. They utilized HoloLens devices to provide visual guidance and interactive features during evacuation. These papers further contribute to the research on mobile applications, time series analysis mobile applications, and augmented reality applications in various domains.

3 Information Gathering and Time Series Analysis

The developed mobile application consists of two key modules: The Information Gathering Module and the Time Series Analysis Module.

3.1 Information Gathering Module

This module allows users to add pins at specific locations within parking lots as shown in Fig. 1. It collects various data associated with each pin, such as temporal variables (e.g., time, date, latitude, longitude), license plate information, and images or videos captured by users as shown in Fig. 2. The module serves as the primary data collection mechanism for the application. As shown in Fig. 2, the image can be uploaded from the device using Pick from device button or it can be captured through device using camera button.

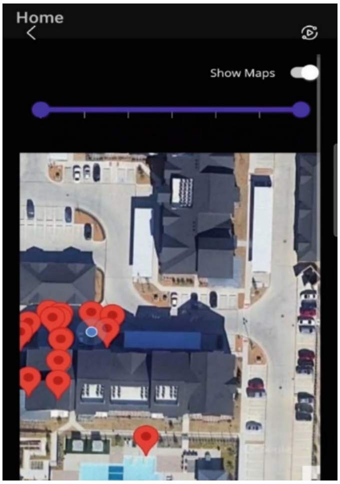

Fig. 2. Capturing image of vehicle at parking lot

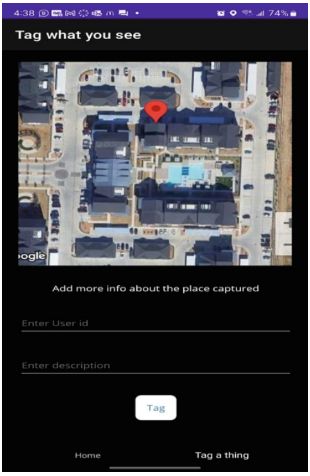

Fig. 3. Updating information of image

For the image captured in Fig. 2, user can enter the username and description of the image and it will be saved in the database. Along with these parameters, date and time of when the image is added along with the current location of the user as shown in Fig. 3. The mobile application gathers parking lot information through its Information Gathering Module.

1. User-Added Pins
   Users can add pins on the mobile application to mark specific locations within the parking lot. These pins serve as references for data collection.
2. Data Collection
   When a user adds a pin at a location, the application collects various data associated with that pin. This includes temporal variables such as latitude, longitude, time, and date, which provide information about when the data was recorded. Additionally, the application can collect text information from the license plate, which helps identify individual vehicles.
3. Image and Video Capture
   Users have the option to capture images and videos at the location using their mobile devices. This feature enables the collection of visual data related to the parked vehicles or the parking area itself.
4. Integration with Data Sources
   The mobile application can integrate with different data sources to gather parking lot information. For example, it can connect to existing parking management systems or databases to retrieve relevant data such as occupancy status, parking restrictions, and reservation information. It can also utilize external data sources, such as real-time traffic data or weather information, to enrich the analysis.

By combining user-added pins, temporal variables, license plate information, and visual data captured through images and videos, the mobile application can collect comprehensive parking lot information. This integration with various data sources allows for a more holistic understanding of parking behavior and facilitates effective time series analysis and anomaly detection. This can bring several benefits to urban parking management:

1. Predicting Parking Demand
   Time series analysis can identify patterns and trends in parking occupancy over time. By analyzing historical parking data, the application can forecast future parking demand during specific periods, such as peak hours or event days. This information helps parking administrators anticipate and allocate resources, accordingly, ensuring optimal utilization of parking spaces.
2. Resource Allocation
   Time series analysis allows decision-makers to understand the utilization of parking spaces at different times, days, or seasons. By identifying high and low occupancy patterns, parking resources can be efficiently allocated. For example, if the analysis reveals consistently low occupancy during certain hours, resources can be redirected to other areas or activities.
3. Anomaly Detection
   Anomaly detection techniques can identify abnormal or suspicious parking behavior in real time. This includes detecting unauthorized parking, parking violations (e.g., parking in restricted areas, disabled spaces, or expired meters), or vehicles exceeding the allowed parking duration. By promptly identifying such anomalies, appropriate actions can be taken, such as issuing warnings or fines, ensuring compliance, and improving overall parking management efficiency.

4. Optimization of Space Usage

   Time series analysis helps in understanding parking patterns and usage trends throughout the day. The application can provide insights into underutilized or over utilized parking areas by analyzing the occupancy patterns. This information allows administrators to optimize space usage, such as redistributing parking spaces, implementing dynamic pricing strategies, or creating incentives to encourage off-peak utilization.
5. Decision Support

   The analysis of time series data and anomalies provides decision-makers with valuable insights for effective decision-making. By visualizing the data and presenting meaningful patterns and outliers, the mobile application enables administrators to make informed decisions regarding parking policies, infrastructure improvements, capacity planning, and enforcement strategies.

3.2 Time Series Analysis Module

The Time Series Analysis Module analyzes the collected data over time to identify parking patterns and detect anomalies as shown in Fig. 4. It utilizes advanced algorithms and techniques to process the temporal data and provide actionable insights for decision-making in parking management.

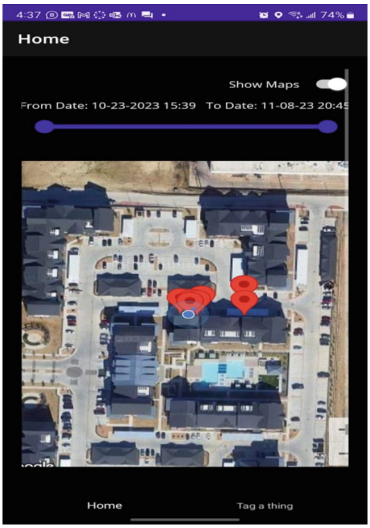

Fig. 4. Time Series Analysis Module

3.3 Data Collection

The mobile application facilitates data collection through user interaction. Users can add pins at desired locations within parking lots, providing reference points for data collection. When a pin is added, the application captures relevant data, including temporal variables, license plate information, and optional images or videos. The mobile application collects various data variables to enable comprehensive analysis and anomaly detection. These variables include:

1. Temporal Variables
   Temporal variables include the date and time of data collection, allowing for analysis of parking patterns over different periods. Additionally, latitude and longitude data provide spatial context to understand the distribution of parking behavior across the parking lot.
2. License Plate Information
   License plate information is collected to identify individual vehicles. This data helps track parking duration, detect unauthorized or abnormal parking, and link the collected data to specific vehicles.
3. Images and Videos
   Users have the option to capture images and videos using their mobile devices. These visual data provide additional context, allowing for visual analysis of parking occupancy, identification of parking violations, and monitoring of the overall parking area condition.

By collecting and analyzing these data variables, the mobile application enables effective time series analysis and anomaly detection, enhancing decision-making capabilities in urban parking management. The mobile application is designed to track the occupancy rate of parking lots over time. By utilizing the data collected through the Information Gathering Module, including temporal variables and license plate information, the application can analyze and monitor the occupancy status of parking lots at different time intervals. It processes the collected data to determine the occupancy status of the parking lot at specific time intervals. It can calculate the number of occupied parking spaces by analyzing the number of vehicles present during each time interval. The collected occupancy data is then analyzed using time series analysis techniques. This analysis helps identify occupancy patterns, trends, and fluctuations over different periods (e.g., hourly, daily, weekly). The mobile application can present the occupancy rate of the parking lot over time through visualizations such as graphs, charts, or heat maps. These visual representations provide a clear understanding of how the occupancy rate changes throughout the day, week, or other defined periods. The application can compare the current occupancy rate with historical data to identify any significant changes or anomalies. This helps in detecting abnormal or unexpected parking behavior. By tracking the occupancy rate of parking lots over time, the mobile application provides valuable insights into parking patterns, peak hours, and overall utilization of parking spaces. This information can assist in making informed decisions regarding resource allocation, parking capacity planning, and optimizing the parking experience for users.

4 System Framework and Implementation

The system architecture consists of multiple components that work together to provide a seamless mobile application experience. Figure 5 demonstrates how the user, devices, camera, and application functionalities are integrated. The user interacts with the application installed on either a phone or tablet and the application opens the map and the pins located in different places fetching them from the database. If the user wants to locate a pin and attach any image at the location, then they could click the image using a camera in the phone/tablet or pick it from the device.

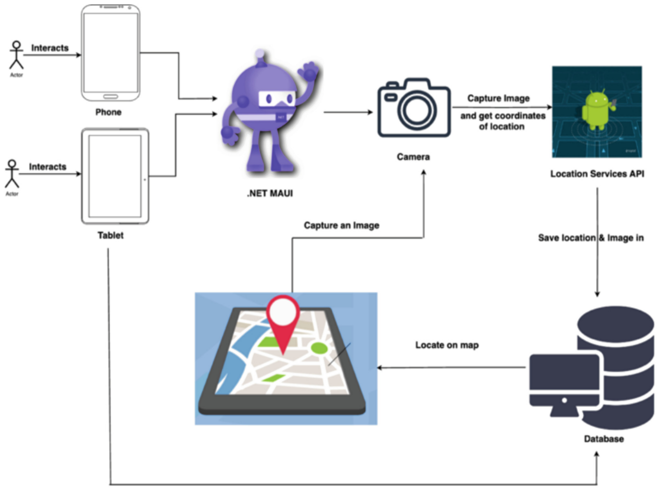

Fig. 5. System Framework diagram of the mobile application

The application layer is built using.NET Multi-platform App UI (MAUI), a framework that enables the development of cross-platform mobile applications using C# and XAML. It provides a robust user interface (UI) development environment, allowing developers to create visually appealing and responsive UI elements. The application layer acts as a bridge between the user and the underlying system components. One of the key features of the application is its integration with the Google Maps API, which offers comprehensive mapping and geolocation services. The Google Maps API enables the application to display maps, markers, and other relevant data to the user. It also provides functionalities such as geocoding (converting addresses to geographic coordinates) and reverse geocoding (obtaining address information from coordinates). By leveraging the Google Maps API, the application can deliver accurate and up-to-date location-based information to the users. The system architecture includes a local database component responsible for secure data storage. This database stores various types of data, including the pins representing different locations on the map and associated information. Additionally, the database stores any images captured by the user using the device's camera or selected from the device's storage. The captured or selected images are linked to the corresponding location pins, allowing users to attach visual content to specific places on the map.

The flow of data within the system architecture is as follows: when the user interacts with the application, the UI layer captures user input and triggers appropriate actions. For example, the user may choose to capture an image using the device's camera or select an image from the device's storage. The application layer handles these actions and securely stores the images in the local database, associating them with the relevant location pins. When the user opens the application, the data access layer retrieves the necessary information from the local database, including the pins and their associated images. This data is then displayed on the user interface, allowing the user to view the map, explore different locations, and access the attached images.

Overall, the system architecture provides a robust and intuitive mobile application experience. It leverages the capabilities of.NET MAUI, Google Maps API, device cameras, and local database storage to enable users to interact with the map, attach images to specific locations, and retrieve and display the collected data seamlessly.

5 Results and Analysis

The time series analysis conducted by the mobile application involves examining the occupancy rate of parking lots over various time intervals. It captures patterns and trends in parking behavior, such as daily or weekly fluctuations in occupancy. This analysis helps identify peak hours of parking demand, periods of low utilization, and recurring patterns that can be used to optimize resource allocation and improve operational efficiency. For example, it may reveal that parking lots experience higher occupancy rates during weekdays compared to weekends, allowing parking managers to adjust staffing or pricing accordingly.

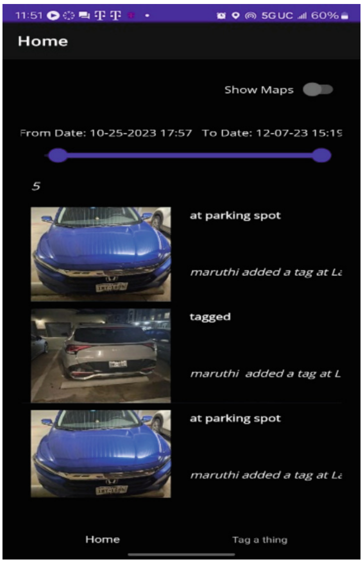

Fig. 6. Time Series Analysis in the Mobile Application

Figure 6 shows data extracted for time series analysis using the mobile device. The mobile application's anomaly detection algorithms play a crucial role in identifying and flagging anomalous behavior in parking lots. This includes instances of unauthorized parking, vehicles exceeding time limits, parking violations, or abnormal occupancy patterns. By promptly identifying such anomalies, parking managers can take appropriate actions, such as issuing warnings or fines, implementing stricter enforcement measures, or investigating potential security concerns. This helps maintain order, ensure compliance with parking regulations, and enhance overall parking lot security and safety. The mobile application extracts meaningful insights from the analyzed parking data, which can guide decision-making in parking management. These insights go beyond occupancy rates and anomalies and provide a deeper understanding of parking dynamics. For instance, the application may reveal the impact of external factors like nearby events or weather conditions on parking patterns. It can identify areas with consistently high or low occupancy, allowing for targeted interventions such as adjusting pricing or expanding parking capacity in high-demand areas. Additionally, the application's analysis can help identify potential inefficiencies in parking operations, such as underutilized spaces or bottlenecks in traffic flow, enabling parking managers to make data-driven improvements.

6 Conclusions

This paper highlights the capabilities and benefits of the developed mobile application for urban parking management. The application utilizes advanced data analysis techniques, anomaly detection, and predictive modeling to provide valuable insights and functionalities. It enables parking managers to predict future parking demands, allocate resources efficiently, optimize space usage, and detect irregularities and violations within parking facilities. By leveraging these features, the application enhances the overall parking experience, improves operational efficiency, and contributes to more sustainable and effective urban parking management. The developed mobile application holds significant importance in the realm of urban parking management. It addresses key challenges faced by parking managers, such as limited parking capacity, high demand fluctuations, inefficient resource allocation, and enforcement issues. By providing accurate predictions, optimizing resource allocation, and enhancing space utilization, the application helps alleviate parking congestion, reduce environmental impacts, and improve overall urban mobility.

The mobile application's integration with existing parking systems and infrastructure further enhances its value and feasibility. By leveraging the investments made in sensor technologies, payment systems, access control mechanisms, and enforcement systems, the application can seamlessly integrate into the existing parking ecosystem, ensuring compatibility and ease of implementation. Moreover, the mobile application's user-centric approach prioritizes the parking experience of individuals. Providing real-time information on parking availability, facilitating convenient payments, and promoting fair parking practices, enhances user satisfaction, reduces the time and effort spent searching for parking, and encourages the use of sustainable transportation options.

Overall, the developed mobile application represents a significant advancement in urban parking management. It leverages data-driven insights, advanced analytics, and seamless integration to optimize parking operations, improve resource allocation, and enhance the parking experience for both parking managers and users. With its potential to reduce congestion, improve efficiency, and contribute to a more sustainable urban environment, the mobile application holds immense importance in the field of urban planning and transportation management. In conclusion, the developed mobile application has the potential to revolutionize the way urban parking is managed. By leveraging advanced technologies, data analysis, and seamless integration, it offers valuable insights, improves operational efficiency, and enhances the overall parking experience. The application holds great promise for addressing the challenges associated with urban parking and can contribute to creating more sustainable, efficient, and user-friendly cities.

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