Real-Time AI-Driven Solutions for Smart Parking Systems

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1. Introduction

Smart parking systems have garnered great interest due to the growing urbanization and the necessity for efficient use of limited parking spaces. Traffic congestion and cruising for vacant parking spaces are major issues caused by inadequate parking facilities. Traditionally, parking has been managed and operated manually, leading to several drawbacks such as high operating costs and management difficulties, inefficiency due to lack of parking space information, increased risk of theft or damage to vehicles in underground parking facilities, and ineffective entry and exit management. The scenario change has been aided by technological advancements in various areas such as sensor technology, IoT, real-time artificial intelligence, and big data analysis, incorporating the software. AI applications, research, and subsequent advancements are addressed in the following discussions.

Over the last decade, underground parking management has become increasingly intelligent and sophisticated. Major technological advancements and research have been made to develop management systems that are more user-friendly, efficient, and automated by analyzing occupancy in underground parking using different techniques, with AI, machine learning, and deep learning. AI is playing a vital role in the development and growth of underground parking. AI-driven smart city parking is a fully automated real-time parking management solution that seeks to increase user convenience, comfort, and parking space utilization while optimizing parking procedures and auxiliary processes, including building entry and exit management and indoor sharing services. A parking occupation prediction and intelligent parking management system are introduced in which vehicle levels, including parking spaces and lanes, are classified and dynamic available space prediction is performed, providing opportunities for intelligent entry guidance for drivers and optimization of entry permissions for facility management. The proposed system deploys AI predictive models and is bolstered by IoT and big data technologies to analyze highly dynamic occupancy status.

1.1. Background and Significance

Parking systems have long been a part of our cities and have evolved with the continuous growth of vehicle ownership. However, with the acceleration of urbanization and economic development, accompanied by an increase in vehicle ownership, parking challenges have come to assume critical dimensions. The size of the global middle class, consumers with more spending power, is expected to increase significantly by 2030. Vehicle ownership and car sales are forecasted to increase substantially from 2015. The increase in urbanization and the ownership of several vehicles in families have led to the difficulty of finding a place to park in our cities due to the increasing volumes of vehicles entering an urban area.

Big-city case studies have revealed that urban traffic congestion, playing a major role in the reduced quality of life, economic growth costs, and environmental pollution of the communities, is dynamic in nature. Parking is a significant factor. Existing parking systems are less effective and involve the development of intelligent solutions that can enhance the current difficulties of parking in city regions. Smart technologies, such as sensors and mobile apps, provide access to detailed data for optimizing the use of car parks and parking spaces. AI-driven data analytics present opportunities to gain a number of insights. AI has begun to offer vital data-driven solutions for myriad parking difficulties by investigating large quantities of data. The efficacy of parking solutions extends to environmental benefits. Proper parking control decreases the urban mileage of trucks searching for parking, which reduces emissions as well. Recently, planners and legislators have given greater focus to parking supply and demand in several Asian countries with the advancement of infrastructure and the blessing of increasing urbanization and motorization.

2. Smart Parking Systems

Over the years, the increasing number of vehicles has also led to many current and planned parking spaces; therefore, smart parking systems have been developed in recent years to effectively overcome parking problems. Smart parking is a system that allows automatic and real-time management of parking space. It is a set of technologies that can monitor individual parking spaces, collect data related to all the parking spaces with parking priorities, and realize efficient optimization of parking space assessment for parking guidance and information. It mainly consists of sensors and actuators embedded in the physical world, communicating hardware through wireless communication protocols, and cognitive software that makes necessary decisions according to the data collected by sensors. In addition, the smart parking management system has a wide range of features such as parking detection for reserved and normal users and violation detection for both reserved and normal users.

As an essential component of smart cities, the development of smart parking systems has drawn the attention of both governments and the research community. The Internet of Things integrates physical devices with communication to enable the exchange of data between physical devices and other systems. In a smart parking system, it provides a secure and easy parking process through two-way communication, interaction, and collaboration between vehicles, sensors, parking spaces, and systems. To streamline this process, advancements have been made to develop mobile applications that can receive sensor information in real time, thus adding value by prioritizing display on mobile applications. These smart parking systems help reduce congestion, improve user satisfaction, and promote efficient use of non-reserved and normal parking spaces in parking structuring. Although smart parking systems have these advantages, there are still some challenges in their development and practical implementation. Several case studies and pilot projects applying smart parking in different cities have been conducted in light of these real-world benefits. This paper provides a comprehensive overview of the essence of smart parking characteristics, technological components, benefits, and concerns. It covers case studies that illustrate the breakthroughs of smart parking projects and the future direction and research gaps required for the development of the solution. In terms of scope, the paper limits itself to on-street or off-street smart parking management solutions supporting both private and controlled parking.

2.1. Overview of Smart Parking Technology

Sensors and devices are the backbone of a smart parking system, which serves to collect parking occupancy data. They can be categorized as active sensors and passive sensors. Active sensors could also include mobile sensors that are employed in the private sector, where the parking owner can track the whereabouts of their vehicles. The data collected from all of these sensors will be provided to an electronic device controller to be processed and eventually shown to the vehicle owner through a parking app or a website. Most smart parking technologies utilize some type of communication devices to provide feedback to the parking users whenever necessary; this could be achieved using wired or wireless communication. Currently, in smart parking systems, communications are often performed utilizing communication protocols that enable real-time availability updates and alerts. Most of them include various communication technologies, which are also utilized for remote access to the sensors when cameras are used. This utilizes Low Power Wide Area Network to provide the communication network with little power consumption. This will prevent the need to periodically recharge or replace the sensors' batteries.

The smart parking system has the potential for wide applications and is generally applicable in practical solutions. For example, parking guidance systems can be easily integrated into pre-existing urban environments as a new public service, aiding in the easy recognition of underutilized spaces and reservations ahead of arrival. Additionally, urban retail districts could employ parking guidance systems to recommend alternative space allocation for drivers, supporting new and/or temporary markets, events, or other public engagements. The use of mobile-based parking payment solutions has been proven to have a positive effect on the customer's parking experience. Dynamic pricing is an additional motivator in the usage of a digital parking service, which informs customers regarding available parking spaces in real-time. By combining existing database information related to customer journeys, parking choices, and compatibility with open data information, cities and regions are able to help inhabitants to a greater extent when faced with the decision of where to park. The payment solution can inform users of the current parking situation in the zones where the parking services are located. The current system follows a service-oriented architecture design and is based on cloud computing technology for data processing, a wireless sensor network for data collection, a database for the storage of parking data, and a smartphone application/mobile technology for the dissemination of parking information to the residents. During this development, we also took into consideration the general context and international state-of-the-art parking in groups, different architectural designs, and methods used for a parking solution, utilizing geo-referencing or location-based technology solutions adapted primarily for service providers. In so doing, we observed that generally they lack full components of an overall integrated parking management solution and also lack explicit forms compared to our approach with affordability and practicability in mind. Moreover, the intuitive user-friendly strategy has been strategically targeted in the designed system; otherwise, it may lead to a higher degree of users finding their parking and subsequent return location.

3. Machine Learning in Smart Parking

A key enabling technology for smart parking systems is machine learning, which is a branch of artificial intelligence dedicated to teaching machines to tackle large amounts of data in a more effective manner and make more accurate decisions based on it. These algorithms can provide valuable insights into relevant data sources, such as historic parking data, traffic management information, and even social media data. It is primarily the use of predictive analytics, which allows for the forecasting of future parking availability based on past and present data, that can help in the management of the off-street parking system. There are various machine learning models that can be used for predictive analytics of parking availability, such as linear regression, autoregressive integrated moving average, support vector machines, and neural networks. However, the accuracy of these algorithms is highly dependent on their input data, which needs to be kept real-time in order to make predictions accurate.

It is important for the machine learning algorithms to be able to improve their predictive accuracy of parking availability based on the input parameters. Additionally, big data has shown that the most successful predictive analytics occur when machine learning models are trained on big data. It is very feedback-driven as it waits for the result and comes up with predictions more accurately. However, a careful approach is needed, since the data produced by cameras and mobile applications is personal and thus sensitive. One potential problem when developing machine learning models is the potential bias present in the data used to create the algorithm. This may generate results that are unfair, reflecting possible prejudice present in the data rather than reality. Several successful projects have implemented machine learning algorithms in parking systems, providing evidence that these methods have the potential to revolutionize the off-street parking system.

3.1. Types of Machine Learning Algorithms Used

Parking solutions have witnessed the use of machine learning algorithms to improve the overall performance of the system. Machine learning algorithms used in this context may be classified as follows. Supervised learning: This type of algorithm is used in making a predictive analysis of parking data. It also classifies unused, nearly full, and full parking bays. They train a model on historical data and then use the same to predict future results. For example, linear regression is being used on available parking data for business reasons. Around 80% of the parking data is being used for training and the rest for testing those trained parameters in this experiment. Similarly, ranking-based linear regression, gradient boosting decision trees, and natural language processing are used in the project. The user reviews are used as input to build the model, and the computed results are correlated with the survey results. All these models predict and rank the preference of the users towards a parking facility. At the same time, supervised learning is used for the classification of parking bays as 'occupied' and 'unoccupied' in the model used in the smart parking system, which uses 8 classes for the training of the available data. The trained binary classifier hyperplane calculated for each possible class plays a major role in categorizing an unknown data point in the testing connected vehicles parking dataset. Using supervised learning to predict the preferential parking facilities replacement option, used, and vacant is enormous compared with the unsupervised learning case. Unsupervised learning: This type of machine learning is used in the project. Parking usage patterns are formed considering the collected facts. It is used to learn the underlying data nature to identify parking and offer instances as input for clustering. It is used in deciding the threshold for specifying outlier parking transactions. For example, clustering methods such as k-means are used to identify parking usage patterns from the dataset. It is mainly implemented as an offline analysis, but its outcomes could be used for distinguishing parking operations and/or as input to create additional classification or regression models. Furthermore, unsupervised learning identifies whether the vehicle is in automatic mode, transit mode, cargo mode, or mixed mode. It then allocates the driver trip to one of the given modes. Reinforcement learning: Reinforcement learning frameworks have been used to capture dynamic decision-making in real time. It is finding its application in parking to arrive at the best decision that will provide an optimum result. For example, it has been used in the study to find the optimal trading strategy in a market parking. Using a suitable action for the user parking scenario is important in each case and hence to decide on a machine learning algorithm to be employed for a parking solution. The application scenario is important as the machine learning method should be focused on matching this scenario.

4. Optimizing Parking Space Allocation

Effective optimization of space allocation can help alleviate parking shortages and reduce congestion significantly. In large urban areas, thousands of parking spaces may be distributed across multiple adjacent facilities. The configurations and availability of these spaces can differ across varied areas based on factors such as location, time, or access permits. Real-time approaches to space allocation utilize a range of heuristics, algorithms, and optimization models to automate space allocation. There have also been some recent attempts to develop a model that can predict the effect of changing any distribution of the system's capacities and adaptively allocate them as needed.

Once the optimum allocation is determined, the parking system can then allocate the space based on real-time data. Parking reservations can also be employed as a tool to dynamically adjust the allocation of parking based both on reservations and the number of bays remaining. Such moves demand the ability to handle partial allocation in real time and anticipate the impact of new transactions on the availability of spaces. There are several instances of the successful implementation of this algorithm in built projects. The primary challenge in such an allocation method arises from compliance management and user adaptability. Another consideration linked to this model is the method of integrating any advanced control system emerging from this with a capacity optimization model that focuses on benefit maximization for the parking operator.

This real-time space allocation shows that other heuristic methods for capacity allocation are capable of adaptive property management research potential in terms of developing parking allocation methodologies. These methodologies form a key part of developing smart parking frameworks that run efficiently. The broad project has shown the potential to efficiently utilize parking spaces with a system developed around innovative algorithms and AI with a goal of maximizing profits. The project also exemplifies the capability to maintain an appropriate level of occupancy, avoiding both congestion and supervising a smooth movement of traffic flow. In this smart parking system, considerable reduction in traffic bottlenecks and associated air pollution in some corridors has been noticed following its implementation. In the vehicle storage lot at the Port of Auckland, the system has shown a positive rise in profit.

4.1. Data Collection and Analysis

In this subsection, we present data collection methods and tools that are necessary to perform parking resource allocation and management. The collection of data provides input for the analysis. Thus, further in the last two subsections, it plays an important role in selecting decision-making models and control algorithms, as well as in developing and assessing multi-strategy optimization. Data are collected from several sources that may be employed in practice: in-ground vehicle sensors, vehicle counting sensors, main underground vehicle counting sensors, in-ground space availability sensors, parking zone occupancy sensors, cameras, mobile apps, or cellular network data.

Modern parking systems are often implemented with one of the above data sources. These real-time data from the different technology sources are used for parking space allocation. Here, reliability and accuracy are critical subjects, as unreliable data may lead to customer dissatisfaction, increase negative word-of-mouth, and reduce the customer's parking experience. Hence, the accuracy and reliability of data need to be carefully planned, collected, monitored, and identified to make informed decisions. The collected data are processed using domain-specific analytics tools to understand possible trends and patterns. Domain-specific analytics is also responsible for continuous space allocation with dynamic data and considering a higher parking demand volume. The challenge with these methods, however, is their ability to integrate directly with the Parking Information System, which already exists in many urban parking areas. Hence, it appears that a supplementary component able to process ordinal or interval measurements and convert them towards an infrastructural Parking Information System, which mostly processes measurements, is needed.

To develop viable decision models for providing a smart parking service, we need more research that addresses these operational issues, such as the range of sensors that provide the best data points in terms of cost, processing estimates, and regional variations, issues of accuracy and sensor placement, and the need to rebuild metadata from information. Based on collected data, the current parking space availability must be updated continuously with respect to market indicators or customer behavior patterns. Understanding customer behavior and analyzing customer preferences and parking demand patterns are essential. These patterns may be related to the departure date and area zoning network, which may be available in a Parking Information System. Hence, this regular pattern should be considered or modeled as a variable of the customer's predicted parking duration with a probability distribution.

5. Reducing Search Time

Many factors can contribute to a vehicle's search time. Once a vehicle arrives at its destination, it must be able to identify a free parking space. In some scenarios, parking spaces are behind cars stationed in front of the same large building, which creates large bottlenecks in areas with a high number of vehicles. This search time can lead to passenger delays, particularly in delivery services that aim to reduce pollution in the city by dispatching smaller vehicles instead of large trucks. There are also situations in which customers choose not to visit some locations because they believe the traffic is too congested. A deterministic approach is based on clients that arrive periodically at a regular time, predict parking possibilities nearby, and request parking in real-time when they are already nearby. However, real life is a lot less regular and predictive. In this case, one possible method to help alleviate the parking space problem is to use knowledge from artificial intelligence to predict in advance a set of available parking spots with information received from sensors placed at strategic locations.

Data can contain information such as light-bound parking spaces. With good management and organization, vehicles could receive hints from an algorithm when they are a few meters away from a location, determining a spot that is available for them according to factors such as the vehicle's geometry and dimensions, the disparity to compliance with parking regulations, and the availability of space. This provides the driver with sufficient confidence to shorten their search with few regulatory risks, avoiding problems such as bottlenecks at entry points or the vehicle being stuck due to traffic. Another approach is to provide clients with a parking reservation, where the parking lot offers a guaranteed, discounted once-per-hour parking rate by associating with the AI algorithm to decide on the price in order to incentivize usage and optimize profits.

5.1. Real-Time Data Processing

Smart parking systems generally consist of a variety of sensors that are distributed across the parking facilities to detect car park occupancy. These sensors transmit car park occupancy information to the backend server where data processing and analytics are carried out. With simple data processing such as aggregating or low-level filtering, many existing car parking solutions can achieve near real-time car park occupancy information with only a few seconds of delay. However, this car park occupancy information does not reflect the turnover rates that are important in real-time traffic flow prediction, dynamic congestion pricing, riot warning, and tourism management. The traffic flow massive dataset includes movements and turning points of each car that passed through the selected thoroughfare in the assessment. With reference to turning points on the map of the city, trip chaining and trip generation results may be derived.

Nowadays, nearly all car parking systems in the market operate as near real-time solutions with some additional expensive deployment of processing resources to cope with processing bottleneck issues. The processing bottleneck problems of these systems could become more severe with an increased number of deployed sensors, an increased frequency of sensor data collection, an increased variety of data analysis functions, and the increasing complexity of these functions. All of this is important as real-time information processing and forecasting could provide additional benefits due to their actionable analysis for analysts, decision makers, service providers, and individual citizen drivers. The travel experience of the latter groups would be improved due to having more car park occupancy information about the parking availability near points of interest.

6. Future Direction

The given parking system is an integral part of the smart city. The enormous promise and expected future of smart parking systems and the trends are as follows: • Data sharing and integration: Emerging parking technologies should be integrated into a range of other smart city systems and activated through APIs. Parking can be integrated with other smart city technologies through smart city dashboards and data platforms, making it part of a wider urban planning solution to urban challenges. • Artificial intelligence and blockchain could solve inefficiencies in parking markets. • Parking: Complete the Parking Innovation and Planning Prioritization phase to develop and deliver the Walking Parking Plan and the Smart Technology Parking Plan – Smart Complete Street for Council endorsement. The Smart Technology Parking Plan will make the most of emerging transportation technology and other national smart city initiatives. • As mobility changes and improved alternatives are developed, convenient parking will remain important as part of a more integrated mobility solution. • Ongoing evolution: Parking solutions must be evolutionary, allowing users to transition rather than revolutionary. Current parking technology platforms have a relatively short life cycle, for example, with mobile applications replacing sensor guidance systems. Ultimately, the future for parking technology is ever more complex, shared urban solutions. The deployment of this technology relies on the collaboration of all transport stakeholders and the response and recovery from the crisis. The following sections detail some barriers to the successful implementation of intelligent transportation systems, such as real-time parking solutions and what they mean for stakeholders. • Infrastructure: Some technologies may require hardware infrastructure with installation implications. Although barriers to edge technology are reducing, some parking sensor hardware may still require associated connectivity, which may lead to associated costs. • Investment: Significant investment in new technologies may be necessary, and stakeholders may be resistant to change without evidence of potential improvements in parking's financial performance.

7. Conclusion

In this paper, we proposed a model for smart parking systems capable of supporting autonomous driving technology. A detailed review of the literature on parking management technologies, and the opportunities that can stem from the adoption of the real-time AI-driven solutions, is provided. It is crystal clear that developing smart parking systems, backed with ICT and IoTs, based on AI, can effectively transform urban parking management and ultimately provide sustainable public and private benefits. The general benefits of smart parking systems may include improving the efficiency in urban logistics, reducing congestion, reducing vibration, noise pollution and local emissions, improving road safety, reducing the time taken to find a vacant parking spot and contributing to a reduction in the amount of land used for car parking. It can also help urban overall vibrancy by increasing productivity, improving public spaces and providing a better user experience when parking. Moreover, it is necessary to educate government bodies and investors that parking is the mice behind the elephants of a successful city and if there no proper attention is geared towards it, it could inverse the growth and vibrancy of cities.

Using appropriate technologies, it is anticipated that smart parking systems can further contribute to parking improvements such as a reduction in the total amount of parking required due to better matching between demand and supply, reduction or minimization in vehicle emissions by reducing vehicle kilometers travelled when motorists search for parking spaces, minimizing greenhouse gas emissions due to both reduced burning of fuel and reduction in the materials required to build car parks. It require few vacancies in some locations. Notably, user perception of congestion could be used to design alternative indicators of congestion. However, critical innovation elements typically hinder the good management of parking facilities such accumulating the data which has increased its value but requires disturbance of private and sensitive spaces to some potential users or applicants. A second consideration for smart parking systems is that innovative technologies are providing the real-time data in which a control approach for desirable outcomes is becoming feasible. In other words, parking management benefits will not be maximized, nor could it pose an attractive concept to address the parking of which the value will continuously increase over time. The subsequent research agenda is therefore multidisciplinary – spanning the intersection of computer science and algorithm design, operations, and behavioral models – as well as being accompanied by highly advanced experimental testbeds that integrate leading technologies and are widely accepted. This roadmap is essential to be realized in order to adapt smart city evolutions with increasing population densities, needs for mobility and transformative trends towards greener energy practices.

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