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Research Article

# Challenges and Opportunities in Smart Parking Sensor Technologies

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**Abstract:** Parking a vehicle in densely populated traffic environments often results in prolonged driving time as drivers search for available spaces, contributing to congestion and environmental pollution. Inefficient parking behavior can be attributed, in part, to the lack of guidance information regarding vacant parking spaces. The implementation of smart parking sensors and technologies offers a solution by guiding drivers to free parking spaces, thereby enhancing parking efficiency. However, it is noteworthy that there are currently no such sensors or technologies employed for open parking lots. This article undertakes a comprehensive review of the existing literature on the utilization of smart parking sensors, technologies, and applications while assessing their suitability for open parking lots. Magnetometers, ultrasonic sensors, and machine vision represent some of the commonly employed sensors and technologies in closed parking lots. Nevertheless, this article recommends the utilization of a combination of machine vision, convolutional neural networks, or multi-agent systems for open parking lots due to their cost-effectiveness and resilience to diverse environmental conditions. While a few smart parking applications indicate the locations of typical open parking lots, none of them provide real-time parking occupancy information, which is crucial for guiding drivers along the shortest route to available space. Consequently, further research in the domains of deep learning and multi-agent systems is essential to develop smart parking applications specifically tailored for open parking lots.

**Keywords**: Smart Parking Sensors; Open Parking Lots; Passive Infrared Sensors; Neural Networks.

## 1. Introduction

Emerging technological advancements have paved the way for innovative solutions in the realm of parking management, particularly in the form of smart parking sensors, technologies, and applications. While considerable attention has been directed towards closed parking environments, where these systems have showcased notable efficacy, there remains a distinct gap in research pertaining to their applicability in open parking lots [1,2]. Open parking spaces, characterized by their expansive nature and exposure to varying environmental conditions, present unique challenges and opportunities for the implementation of smart parking solutions [3,4]. The potential benefits of deploying smart parking systems in open parking areas are substantial. By offering real-time guidance to drivers seeking available parking spaces, such technologies have the potential to alleviate congestion, optimize parking utilization, and reduce the detrimental environmental effects associated with excessive driving and inefficient parking behaviors. Moreover, the integration of intelligent sensors and technologies holds promise in enhancing the overall parking experience for both drivers and parking facility operators, fostering increased convenience, efficiency, and sustainability [6,7]. A graphical representation of smart parking approaches versus the usage of approaches has been illustrated in Figure 1.

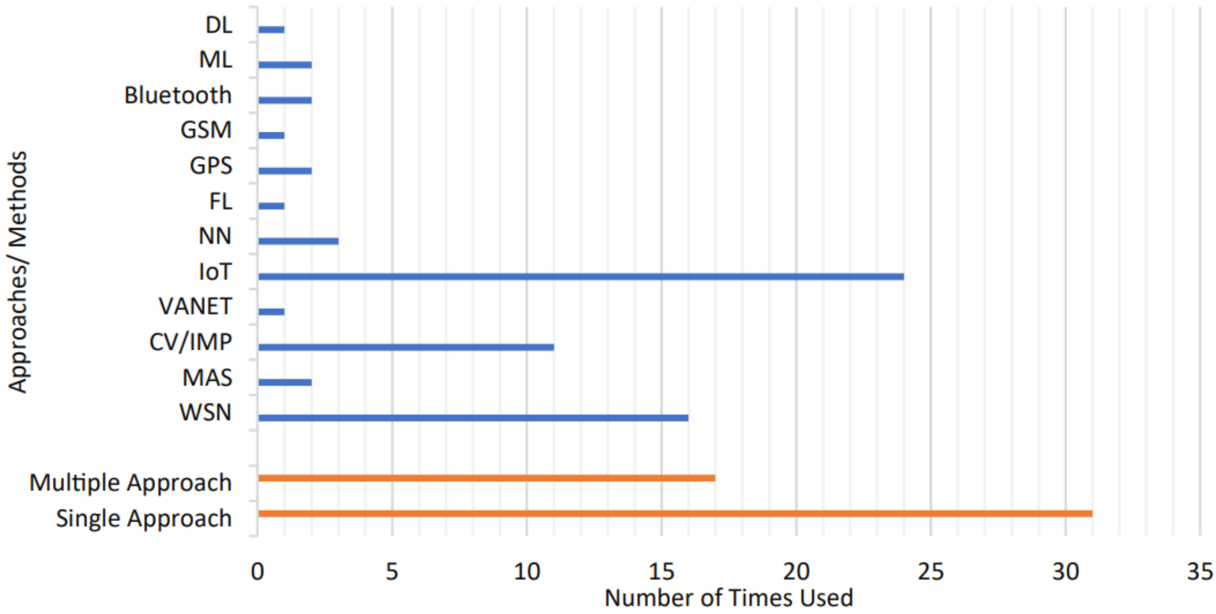


**Figure 1**. Technological approaches of different smart parking.

In this context, in urban settings characterized by high population density, the availability of parking spaces frequently falls short of the number of vehicles present, resulting in a scarcity of parking facilities [8]. Extensive research has demonstrated that in traffic-congested environments worldwide, a substantial proportion of drivers, ranging from 30% to 50%, engage in the quest for unoccupied parking spaces. Previous studies have revealed that drivers typically spend anywhere from 3.5 to 14 minutes in their search for a parking spot. The repercussions of this situation are manifold, including driver frustration, increased risk of accidents, missed business opportunities, traffic congestion, and heightened air pollution levels. Congestion tends to manifest particularly during peak traffic periods when traffic density reaches its zenith. To illustrate the magnitude of the issue, consider a city with an approximate population of 50,000 inhabitants, which typically accommodates an average of 250 parking spaces within a designated parking lot. The associated annual cost of maintaining these parking spaces amounts to approximately 216,000 US dollars [9].

To mitigate the issues of parking-related congestion and air pollution, public transportation options such as buses and metros have been proposed as alternatives. Nevertheless, private vehicles continue to be utilized for the sake of convenience. To address the challenge of carbon emissions, a viable solution entails the replacement of conventional fuel-powered vehicles with electric counterparts. The complete transition to electric vehicles is expected to be a lengthy process [10]. Even with the adoption of electric vehicles, the act of cruising in search of an available parking space remains time-consuming and contributes to congestion. One potential remedy to this issue lies in the realm of driverless cars, a burgeoning technology currently under development [11,12]. Additionally, the implementation of Vehicle-to-Vehicle (V2V) technology holds the potential to enhance the safety of driverless vehicles across the board. However, the successful deployment of automated driverless vehicles hinges upon a confluence of technologies, including Global Positioning System (GPS), sensors, and V2V communication systems. Given the magnitude of these technological advancements and the need for widespread adoption, it is foreseeable that the complete replacement of existing vehicles with automated driverless counterparts will likely span several decades [13-23].

In this paper, various communication models for smart parking systems are investigated, considering factors such as the number and placement of occupancy data collators, hybrid power cycles, and data aggregation strategies. Additionally, a streamlined data format is proposed to optimize the dissemination of information. Through extensive simulation studies, it is determined that a multi-collator model, combined with a data superimposition technique, proves to be the most effective approach for achieving an efficient smart parking system. According to Paidi et al. [24] highlight the limitations in implementing existing sensors and technologies for open parking lots, proposing a robust multi-agent approach to address these gaps. Similarly, other researchers [25,26] categorize parking systems based on the services they provide, including parking reservation, guidance, and crowdsourcing. In reference, Fahim et al.'s survey [27] identifies several different types of Smart Parking Systems based on sensing technology (vision-based/GPS), communication method (Bluetooth/WSN), and learning models employed (ML/Fuzzy). Across these smart parking systems categories, a common layered architecture is defined, consisting of a sensing layer at the bottom, an application layer at the top, and a communication layer bridging the two [28, 29]. Additionally, Al-Turjman et al. [30] introduce a middleware layer responsible for aggregating data from sensors deployed throughout the parking lot, further enhancing the smart parking systems architecture.

Despite the evident advantages, the scholarly literature on smart parking sensors, technologies, and applications for open parking remains limited. The existing body of research primarily focuses on closed parking lots, employing diverse sensors such as magnetometers, ultrasonic sensors, and machine vision technologies. However, a comprehensive exploration of the suitability and effectiveness of these sensor technologies for open parking environments is yet to be undertaken. Thus, this article aims to bridge this research gap by critically reviewing the available literature on smart parking sensors, technologies, and applications, with specific emphasis on their feasibility and potential implementation in open parking spaces. By examining the strengths and limitations of existing sensor technologies and exploring novel approaches such as machine vision, convolutional neural networks, and multi-agent systems, this research endeavors to provide valuable insights into the development of cost-effective, resilient, and efficient smart parking solutions for open parking lots.

The paper is structured as follows: **Section 2** provides a comprehensive discussion on smart parking tools. **Section 3** focuses on the types of smart parking sensors, specifically examining the different sensor technologies employed to detect vehicle presence and occupancy in parking spaces. Building on this, **Section 4** presents an in-depth analysis of the various sensor technologies utilized in smart parking systems, including ultrasonic sensors, magnetic sensors, and infrared sensors. **Section 5** explores the wide range of smart parking applications, showcasing how these technologies are applied in real-world scenarios to optimize parking operations and provide convenient parking solutions for users. In **Section 6**, the challenges and opportunities in the field of smart parking are discussed, shedding light on the potential areas of improvement and growth in this domain. Finally, **Section 7** provides a comprehensive conclusion that summarizes the key findings and contributions of the paper.

## 2. Smart Parking Tools

Smart parking tools refer to a range of technological solutions designed to optimize and streamline the parking experience. These tools leverage advanced sensors, data analytics, and communication systems to provide real-time information and guidance to drivers, improving parking efficiency and reducing congestion [31-33]. Some common smart parking tools include:

- Smart Parking Sensors: These sensors are installed in parking spaces to detect occupancy. They can provide accurate and up-to-date information on available parking spaces, enabling drivers to locate vacant spots quickly.
- Mobile Applications: Mobile apps equipped with smart parking features allow users to access real-time parking information, including availability, pricing, and reservation options. These apps often integrate with GPS technology to guide drivers to the nearest open parking spaces.
- Parking Guidance Systems: These systems use dynamic signage or mobile apps to guide drivers to available parking spaces within a parking facility. They provide real-time information on space availability and direct drivers to the most convenient parking areas.

- Automated Payment Systems: Smart parking tools often include cashless payment systems that allow drivers to pay for parking electronically. This can be done through mobile apps, payment kiosks, or vehicle-mounted devices, reducing the need for physical payment transactions.
- Data Analytics and Management Platforms: These platforms collect and analyze parking-related data, such as occupancy rates, duration of parking, and traffic flow. This information can be used to optimize parking operations, allocate resources effectively, and make data-driven decisions for future planning.
- Smart Parking Meters: Advanced parking meters enable drivers to pay for parking using various payment methods, such as credit cards, mobile wallets, or prepaid parking cards. These meters often integrate with back-end systems to provide real-time payment verification and enforcement.
- License Plate Recognition Systems: These systems use cameras and optical character recognition technology to read and record license plate information. They can be used for parking enforcement, monitoring parking duration, and facilitating automated access control in parking facilities.

The deployment of smart parking tools aims to enhance the overall parking experience, reduce traffic congestion, optimize space utilization, and promote sustainable transportation practices. In this regard, parking tools have emerged as essential solutions for addressing the challenges associated with parking in urban environments. These tools encompass a wide range of technologies, sensors, and applications designed to optimize parking space utilization, enhance the overall parking experience, and contribute to more sustainable mobility. Throughout this paper, authers have explored various smart parking tools, including smart parking sensors, navigation systems, reservation and booking platforms, and real-time data analytics. These tools offer benefits such as real-time parking availability information, efficient navigation of vacant parking spaces, seamless payment options, and improved parking space management. Smart parking sensors, such as magnetometers, ultrasonic sensors, and microwave radar, enable accurate detection of vehicle occupancy in parking spaces. These sensors play a crucial role in providing real-time data on parking availability, helping drivers locate vacant parking spaces more efficiently and reducing traffic congestion. Additionally, navigation systems integrated with smart parking tools provide turn-by-turn directions to available parking spaces, optimizing routes and minimizing the time spent searching for parking. Reservation and booking platforms allow users to secure parking spaces in advance, ensuring convenience and reducing the stress of finding parking in high-demand areas [34-36].

Moreover, the integration of data analytics and real-time monitoring enables parking lot operators and authorities to make informed decisions about parking space management, optimizing space utilization, and improving overall efficiency. However, the successful implementation and adoption of smart parking tools require collaboration between stakeholders, including city planners, parking operators, technology providers, and users. It is essential to address challenges such as privacy concerns, data security, and infrastructure requirements to fully leverage the potential of smart parking tools. Continuous advancements in technology, including artificial intelligence, machine learning, and the Internet of Things (IoT), will further enhance the capabilities of smart parking tools. These advancements will enable more accurate parking occupancy detection, better predictive analytics, and seamless integration with other mobility services. In conclusion, smart parking tools provide innovative solutions to optimize parking space utilization, improve the parking experience for drivers, and contribute to more efficient and sustainable urban mobility [37-40].

## 3. Type of Smart Parking Sensor

One crucial component of smart parking systems is the smart parking sensor, a technological device designed to monitor and detect the occupancy status of parking spaces. These sensors play a vital role in providing real-time data on parking space availability, enabling drivers to make informed decisions and optimize their parking experience [41,45]. Various types of smart parking sensors have been developed, each employing distinct mechanisms and technologies to accurately detect vehicle presence.

This introduction explores some of the commonly used smart parking sensor types, highlighting their key features and applications in modern parking management systems.

A. *Passive Infrared Sensors*

Passive infrared sensors, a type of smart parking sensor, possess the capability to detect alterations in energy levels, allowing for the identification of parking space occupancy when a vehicle is present. These sensors discern changes in energy patterns caused by the introduction of a vehicle or an individual standing above the sensor. Furthermore, by assessing the magnitude of energy fluctuations, these sensors can effectively identify and isolate anomalous data points. However, it is essential to acknowledge that passive infrared sensors are susceptible to environmental conditions and their accuracy may be compromised in the presence of adverse weather phenomena such as snow or rain. Moreover, the installation of passive infrared sensors typically necessitates their placement either beneath the ground or on the ceiling, thereby requiring substantial financial investment for procurement and ongoing maintenance. Consequently, while these sensors prove suitable for closed parking lots situated within structures, they may not be appropriate for outdoor open parking spaces.

*B. Active Infrared Sensors*

Active infrared sensors represent a type of smart parking sensor that functions by emitting infrared energy and subsequently detecting objects or vehicles based on the energy reflected. These sensors exhibit sensitivity to variations in environmental conditions, including precipitation such as rain or snow. Consequently, it becomes imperative to install these sensors in all parking spaces, thereby necessitating significant investment and ongoing maintenance costs. The widespread deployment of sensors throughout parking areas facilitates the accurate determination of parking occupancy status. Typically installed overhead, active infrared sensors find suitability in enclosed indoor parking lots. However, due to their susceptibility to environmental changes, these sensors are not deemed suitable for implementation in open parking lots.

*C. Ultrasonic Sensors*

Ultrasonic sensors, as a type of smart parking sensor, operate by emitting sound waves within the frequency range of 25 to 50 kHz and detecting objects based on the energy reflected from these waves. Typically mounted on the ceiling, these sensors exhibit sensitivity to environmental changes, including rain and snow. Consequently, they prove suitable for implementation in indoor parking lots rather than open parking areas. By analyzing the distance at which the sound waves are reflected, ultrasonic sensors can effectively differentiate between vehicles and individuals. To obtain accurate parking occupancy status, it is necessary to install these sensors on top of each parking space. While ultrasonic sensors themselves are available at a relatively low cost, the long-term expenses associated with installing and maintaining multiple sensors, as well as connecting them to a grid, can be significant. Wireless ultrasonic sensors are also utilized for collecting parking occupancy data, employing wireless sensor networks such as the ZigBee protocol or similar systems. However, wireless sensors entail periodic maintenance costs. Another study explores the application of ultrasonic sensors on a drive-by vehicle, collecting parking occupancy information at regular intervals. Nevertheless, it is important to note that real-time parking occupancy information cannot be obtained through the drive-by-vehicle approach.

*D. Parking guidance systems*

Parking guidance systems represent an additional smart parking solution that furnishes drivers with information regarding the availability of parking spaces through display screens typically positioned in proximity to the parking lots. To ascertain the number of vehicles within a parking lot, inductive loop detectors or visual cameras can be installed at its entrance and exit, with the resulting vehicle count displayed on the screens. Nonetheless, these systems do not guide drivers regarding specific vacant parking spaces. Consequently, there remains a likelihood that drivers may spend a significant amount of time searching for an unoccupied space before successfully finding one. It is only after consulting the display screens that a driver can make an informed decision about the availability of parking within the designated parking lot. Given that the deployment of sensors or visual cameras is primarily focused on gathering vehicle count data, the associated costs for installation and maintenance are relatively minimal, rendering these systems suitable for implementation in open parking lots.

*E. Radio-frequency identification (RFID)*

Radio frequency (RF) tags are employed as a means of identifying vehicles, with each vehicle being assigned a unique RF tag for identification purposes. At the entrance of a parking lot, a transceiver and antenna are installed to identify the RF tag and grant the vehicle permission to occupy a parking space. These systems find suitability in controlled, enclosed, and indoor parking lots. However, they are not well-suited for open parking lots, as they lack the necessary access restrictions typically found in controlled environments. The use of RFID (Radio Frequency Identification) technology allows for the authorization of vehicle movement within a parking lot. Nevertheless, it does not provide detailed information regarding individual parking occupancy status nor does it assist drivers in locating available parking spaces.

*F. Microwave Radar*

A microwave radar system functions by transmitting a microwave beam and subsequently estimating the velocity of a moving target based on the reflected signal. However, it should be noted that this type of radar is unable to detect stationary objects. To overcome this limitation, the implementation of dual microwave Doppler radar can be considered, as it has the capability to detect both moving and stationary vehicles. These radars can be mounted or positioned beneath the surface to facilitate vehicle detection. Unlike other sensor types, microwave radars are not significantly affected by environmental conditions, enabling their utilization in both open and enclosed parking lots. To obtain accurate parking occupancy status, it is necessary to install these microwave radars in every parking space. However, the widespread implementation and maintenance of these radars on a large scale can be costly.

*G. Magnetometers*

Magnetometers are sensors that facilitate the detection of vehicles by sensing variations in the electromagnetic field. To accurately detect vehicle presence, these sensors are typically positioned beneath the surface, in close proximity to the vehicles themselves. Magnetometers are known for their insensitivity to environmental factors. Consequently, they are well-suited for implementation in both open and enclosed parking lots. Wireless magnetometer sensors with extended battery life, lasting for several years, are available and can be utilized to capture real-time parking occupancy information. For comprehensive monitoring of parking spaces, it is necessary to install these sensors beneath each parking space. However, the installation and maintenance of these sensors on a large scale can be financially burdensome.

## 4. Type of Sensor Technologies

Sensor technologies play a pivotal role in assisting drivers in locating and occupying available parking spaces. Detailed descriptions of these technologies are provided in the sections [46-51].

*A. Vehicular ad hoc Networks*

The aforementioned system utilizes wireless communication devices to offer a range of services, including smart parking and antitheft functionalities. In this system, roadside units (RSUs) are strategically positioned throughout parking lots, while vehicles are equipped with on-board units (OBUs). The registration of OBUs and RSUs falls under the responsibility of a trusted authority. Consequently, when a vehicle approaches a parking lot equipped with RSUs, the OBU receives navigational information directing the driver to an available parking space. Additionally, OBUs can aid vehicles in collision avoidance during driving, a feature commonly integrated into self-driving vehicles. These devices exhibit insensitivity to environmental conditions, rendering them suitable for deployment in both closed and open parking lots. Thus, it is important to note that the installation and maintenance of RSUs within parking lots can be costly [52]. However, to ensure accurate parking occupancy data and navigational information, all vehicles must be equipped with OBUs. Failure to install OBUs in some vehicles may introduce errors in the parking occupancy data. Alerting drivers about traffic and road conditions, and other related aspects are essential to safety. To accomplish this, timely and accurate information delivery is crucial. Emergencies can be prevented by exploiting the instruments supplied by VANETs technologies—in other words, all information related to vehicle mobility, such as speed, the direction of vehicles' travel, vehicle density, etc., which are gathered by using Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I). Figure 2, Generalized architecture in vehicular ad hoc networks (VANETs). Table 1, presents the implementation of diverse communication and networking technologies, along with the utilization of various user interfaces, in smart parking.

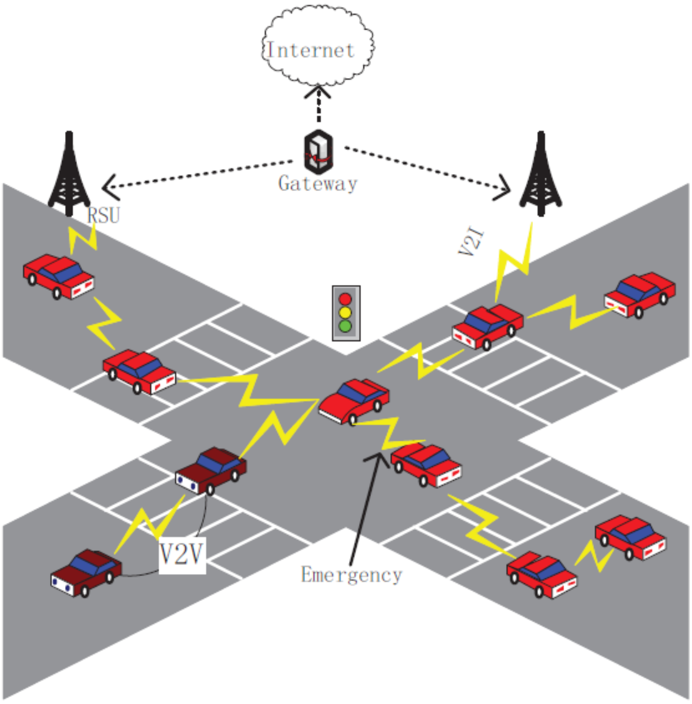


**Figure 2.** Generalized architecture in vehicular ad hoc networks (VANETs) [53].

*B. Global Positioning System*

The utilization of Global Positioning System (GPS)-based navigational directions aids drivers in locating and occupying vacant parking spaces by guiding the shortest or optimal route from their current location. However, GPS alone does not possess the capability to gather real-time occupancy information of parking spaces. In a particular study, parking space occupancy was estimated using historical occupancy data, and navigational directions to the estimated parking space were subsequently provided through GPS. The accuracy of GPS systems equipped with a single-frequency receiver is typically within the range of ≤7.8 meters. On the other hand, the use of a dual-frequency receiver can significantly enhance accuracy, with measurements reaching below 0.71 meters. A standard parking space typically spans between 2.3 and 2.7 meters, and it is worth noting that most smartphones are equipped with single-frequency receivers, which are prone to higher positioning errors compared to dual-frequency receivers. Dual-frequency receivers are commonly utilized in military applications to achieve greater accuracy. It is important to recognize that GPS signals may encounter errors when obstructions such as tall structures, walls within buildings, or subterranean environments obstruct the signal. Consequently, navigational directions relying solely on GPS can be subject to errors when utilized in closed indoor parking lots. Conversely, the usage of GPS is more suitable for outdoor open parking lots, where the likelihood of signal obstruction is reduced. The accuracy of GPS signals is also contingent upon the availability and visibility of satellites.

**Table 1.** The implementation of diverse communication and networking technologies, along with the utilization of various user interfaces, in smart parking.

| Communication/Networking Technologies in Smart Spark | | User Interface in Smart Spark | | |
|---|---|---|---|---|
| **Sensor Network** | **User Network** | **Web Application** | **Smart Phone Application** | **Vehicle Information Communication System** |
| ZigBee | WiFi/3G Networks | | | * |
| WiFi/Ethernet | - | * | * | |
| WiFi + ZigBee | WiFi/3G Network | * | * | |
| LAN (Ethernet) ZigBee | Cellular Networks | | * | * |
| Cellular Networks | Cellular Networks | * | * | |
| WiFi mesh | - | * | | |
| Wireless/Wired | - | | * | |
| GPRS & IEEE 802.15.4 With Digimesh | WiFi/GPRS | | * | |
| WiFi (ESP8266) | - | | * | |

*B. Machine Vision*

Machine vision encompasses the utilization of visual cameras for tasks such as license plate recognition (LPR) and parking lot occupancy identification through the application of machine vision techniques. For LPR, a visual camera is positioned near the entrance of a closed parking lot. By analyzing the number of vehicles entering and exiting, it becomes possible to obtain a count of vacant parking spaces. However, this system does not provide information on the occupancy status of individual parking spaces. Continuous video processing of a parking lot using a camera is not ideal due to the requirement for the constant transfer of large bandwidth data. To overcome this challenge, it is advisable to divide the video into periodic images at specified intervals and frame rates, enabling the continuous monitoring of the parking lot. To detect parking space occupancy, an overhead camera can be installed within a parking lot, and relevant image detection algorithms can be employed to segment vehicles and determine parking space occupancy. Publicly available datasets such as PKLot comprise a significant number of outdoor parking lot images. In one study, a support vector machine classifier achieved an accuracy of 89% on their test dataset. Other image classification algorithms, such as logistic regression and Viola and Jones, also demonstrated higher accuracy results. A camera-based system is well-suited for open parking lots, as it can effectively cover a large number of parking spaces. Nevertheless, it is important to acknowledge that cameras are susceptible to limitations such as occlusion, shadow effects, distortion, and changes in lighting conditions. These limitations can be mitigated through the incorporation of 3D scene information. Due to the ability of a limited number of cameras to cover a substantial number of parking spaces, the associated costs are considered relatively minimal.

*C. Multi-Agent Systems*

Multi-agent systems encompass a comprehensive approach that utilizes various components, including sensors, mobile devices, algorithms, and visual cameras, among others. These systems possess the capability to incorporate user preferences, importance, and other relevant factors to facilitate the identification of vacant parking spaces for drivers. Consequently, multi-agent systems serve as a foundational framework for automating smart parking systems. Users can select a parking space by utilizing mobile or web applications, taking into account their importance and preferences. Based on these factors, a suitable parking space is determined, and the user is provided with navigational information to reach the selected space. To implement the architecture, Java tools such as JaCaMo and environments like CArtAgo can be employed. Instead of traditional sensors, machine vision systems or Vehicular Ad-hoc Networks (VANETs) can be utilized, offering flexibility in choosing the most suitable technology for occupancy detection. The architecture supports the integration of multiple systems, making it adaptable to both open and enclosed parking lots. The overall cost will depend on the specific technology employed to identify the occupancy status of parking spaces.

*D. Neural Networks*

Neural networks, inspired by the complex structure of the human nervous system, serve as data processing systems that have evolved. Various types of neural networks have been developed, including fuzzy neural networks, fluid neural networks, feed-forward neural networks, and convolutional neural networks. These networks can be combined with machine vision techniques to achieve automation in parking systems. One notable application of neural networks is in the efficient recognition of license plates in real-time videos. In a particular study, separate images captured during morning and night were used to train a two-layered feed-forward network with hidden sigmoid neurons, resulting in the accurate detection of available parking spaces. Deep learning, a subfield of machine learning, employs neural networks for object detection and classification. Convolutional neural networks (CNNs) are a notable advancement in this domain, as they excel in image analysis tasks. Recent research has successfully utilized CNNs in conjunction with machine vision to efficiently capture parking occupancy information. Additionally, CNNs have been employed to enable self-driving vehicles, where the network is trained using a set of interconnected cameras to observe the road environment. Through limited training, the vehicle equipped with a convolutional neural network demonstrated the ability to navigate parking lots and roadways even in the absence of lane markings. These neural network technologies serve as powerful tools for data processing, particularly in scenarios that do not necessitate real-time data capture. Therefore, they find suitability in both open and enclosed parking lots, with relatively minimal associated costs.

*E. Fuzzy Logic*

Fuzzy logic represents an approach that incorporates multivalued logic to enable more nuanced evaluations. It can be utilized to develop forecasting models based on sample data. Similar to neural networks, fuzzy logic finds application in multi-agent systems. In one study, a dataset comprising information on parking space availability over a span of five days was used with machine vision to predict the availability of parking spaces on future dates through the implementation of fuzzy logic. Fuzzy logic supports autonomous decision-making by providing information on the availability of parking spaces. However, it is important to note that forecast models may lack accuracy unless validated using real-time data. Therefore, combining fuzzy logic models with machine vision or sensor technologies can enhance the overall system's accuracy. These systems are well-suited for both open and enclosed parking lots. The associated costs are minimal when image processing is employed alongside fuzzy logic to estimate available parking spaces for future time periods while also providing real-time information on parking space availability [54-68]. Since this technology does not require real-time data capture, it can be successfully utilized in both closed and open parking lots with minimal financial investment.

## 5. Smart Parking Applications

Smart parking applications refer to software applications designed to enhance the parking experience by providing real-time information and convenient services to drivers. These applications leverage technology and data to optimize parking space utilization, reduce congestion, and improve overall efficiency in parking management. Some key features and functionalities commonly found in smart parking applications include:

- Real-time parking availability: Smart parking applications provide drivers with real-time information about available parking spaces in specific areas or parking lots. This helps drivers locate vacant parking spots quickly and reduces the time spent searching for parking.
- Reservation and booking: Some applications allow users to reserve and book parking spaces in advance, ensuring they have a guaranteed spot upon arrival. This feature is particularly useful for high-demand areas or events where parking availability may be limited.
- Navigation and guidance: Smart parking applications often integrate navigation systems to provide drivers with turn-by-turn directions to the nearest available parking spaces. These navigation features help optimize routes, minimize traffic congestion, and guide drivers efficiently to their desired parking destination.
- Payment and mobile transactions: Many smart parking applications enable cashless payments, allowing drivers to conveniently pay for their parking using mobile payment methods. This eliminates the need for physical cash or parking meters, streamlining the payment process.
- Parking space monitoring and management: Smart parking applications enable parking lot operators or authorities to monitor and manage parking spaces more effectively. This includes features such as occupancy tracking, enforcement of parking regulations, and data analytics to optimize parking operations and maximize space utilization.
- Parking reminders and alerts: Applications may offer features to set parking reminders, notifying drivers when their parking time is about to expire. Additionally, users can receive alerts regarding parking restrictions, such as street cleaning or time-limited parking zones, to avoid penalties.
- Integration with other services: Smart parking applications can integrate with other services, such as ride-sharing platforms, public transportation information, or electric vehicle charging station locations, to provide a holistic mobility experience for users.

In this direction, smart parking applications have revolutionized the way drivers navigate and utilize parking spaces. These applications leverage advanced technologies, such as real-time data, navigation systems, and mobile connectivity, to provide users with valuable information and convenient services. By offering real-time parking availability, reservation and booking options, navigation and guidance, and seamless payment methods, smart parking applications enhance the overall parking experience for drivers. These applications also benefit parking lot operators and authorities by enabling efficient parking space monitoring, management, and optimization. Through features like occupancy tracking and data analytics, parking resources can be utilized more effectively, leading to reduced congestion, improved traffic flow, and increased revenue generation. Moreover, smart parking applications contribute to sustainable mobility by minimizing unnecessary driving time and reducing environmental impact. By guiding drivers directly to available parking spaces, these applications help to alleviate traffic congestion, decrease fuel consumption, and lower carbon emissions.

However, the successful implementation and adoption of smart parking applications require collaboration between stakeholders, including city planners, parking lot operators, technology providers, and users. Furthermore, ongoing advancements in sensor technologies, artificial intelligence, and connectivity will continue to enhance the capabilities and effectiveness of these applications. As urban populations grow and parking becomes increasingly scarce, smart parking applications offer a promising solution to optimize parking space utilization, improve user convenience, and contribute to smarter, more sustainable cities.

## 6. Challenges and Opportunity

Smart parking sensors, technologies, and applications have emerged as promising solutions for addressing the challenges associated with parking in urban environments. While these innovations offer numerous benefits, they also face certain challenges that need to be overcome for successful implementation. This article explores the challenges and opportunities for smart parking sensors, technologies, and applications, shedding light on the key areas that require attention and the potential benefits that can be realized.

*A. Challenges*

- Environmental Factors: Open parking lots are exposed to various environmental conditions such as extreme temperatures, rain, snow, and dust. These conditions can affect the performance and accuracy of smart parking sensors and technologies, requiring robust and weather-resistant solutions.
- Connectivity and Network Coverage: Open parking lots often lack consistent connectivity, making it challenging to establish reliable communication between sensors, applications, and parking management systems. Ensuring seamless connectivity and network coverage is crucial for real-time data transmission and the effective operation of smart parking systems.
- Scalability and Coverage: Open parking lots can span large areas with numerous parking spaces. Ensuring comprehensive coverage and scalability of smart parking sensors and technologies to accommodate a high volume of parking spaces poses a challenge. The deployment of a sufficient number of sensors and the ability to handle data from multiple sources is essential.
- Cost and Return on Investment: Implementing smart parking systems in open parking lots can involve significant costs, including sensor installation, infrastructure setup, and maintenance. Balancing these expenses with the potential benefits and return on investment can be a challenge, especially for open parking lots with fluctuating demand.
- User Adoption and Behavior: Encouraging drivers to adopt and utilize smart parking applications and technologies is crucial for the success of these systems. Overcoming resistance to change, promoting awareness, and educating users on the benefits and ease of use are challenges in driving user adoption and changing parking behaviors.
- Privacy and Data Security: Smart parking systems collect and process sensitive data, including vehicle information and user details. Ensuring robust privacy measures and data security protocols to protect user privacy and prevent unauthorized access or misuse of data is a critical challenge.
- Integration and Interoperability: Open parking lots often involve multiple stakeholders, including parking lot operators, municipalities, and technology providers. Ensuring seamless integration and interoperability between different smart parking systems, applications, and management platforms can be challenging due to the diverse technologies and proprietary solutions in use.
- Maintenance and Upgrades: Regular maintenance and timely upgrades of smart parking sensors and technologies are essential for their optimal performance. Managing maintenance schedules, addressing technical issues, and implementing necessary upgrades can be complex, particularly in large-scale open parking lots.
- Data Management and Analytics: Handling and analyzing the large volume of data generated by smart parking systems is a challenge. Effectively managing and processing data, extracting valuable insights, and utilizing advanced analytics techniques to optimize parking operations and improve decision-making require robust data management and analysis capabilities.

The challenges and opportunities surrounding smart parking sensors, technologies, and applications present a dynamic landscape for the future of parking management. While challenges such as connectivity, scalability, and cost need to be addressed, the potential benefits and opportunities are immense. By overcoming connectivity issues and ensuring robust network coverage, smart parking systems can provide real-time data and improve the overall parking experience. Scalability challenges can be tackled by developing solutions that can handle a large volume of parking spaces, while cost considerations can be balanced by assessing the long-term benefits and return on investment.

*B. Opportunities*

Improved Parking Efficiency: Smart parking sensors, technologies, and applications offer the opportunity to enhance parking efficiency in open parking lots. By providing real-time information about available parking spaces, drivers can quickly locate vacant spots, reducing the time spent searching for parking and minimizing traffic congestion.

- Enhanced User Experience: Smart parking tools provide an opportunity to enhance the overall user experience in open parking lots. Features such as real-time parking availability, reservation options, and navigation assistance help drivers plan their parking, leading to a smoother and more convenient parking experience.
- Optimal Space Utilization: Smart parking systems enable better utilization of parking spaces in open lots. By accurately monitoring parking occupancy and implementing efficient space management strategies, such as dynamic pricing or time-based restrictions, open parking lots can maximize the utilization of available spaces.
- Reduced Traffic Congestion: Efficient parking solutions can help reduce traffic congestion in and around open parking lots. By guiding drivers to available parking spaces and minimizing the time spent circling for a spot, smart parking tools contribute to smoother traffic flow and reduced congestion.
- Sustainability and Environmental Benefits: Smart parking technologies provide an opportunity to promote sustainable mobility. By optimizing parking operations, reducing vehicle idling, and guiding drivers to the nearest available parking spaces, smart parking tools can help minimize carbon emissions and contribute to a greener environment.
- Integration with Other Mobility Services: Smart parking systems offer the opportunity for integration with other mobility services, such as ride-sharing or public transportation. By providing information about parking availability near transit hubs or integrating parking payments with mobility apps, open parking lots can enhance the overall mobility ecosystem.
- Data-Driven Decision-Making: Smart parking sensors and technologies generate a wealth of data that can be leveraged for data-driven decision-making. By analyzing parking patterns, demand trends, and user behavior, parking lot operators can make informed decisions to optimize parking operations, allocate resources effectively, and improve overall performance.
- Seamless Integration with Smart Cities: Smart parking technologies align with the vision of smart cities, creating opportunities for seamless integration with other urban systems. Integration with traffic management systems, intelligent transportation networks, or urban planning initiatives can lead to holistic and interconnected urban environments.
- Innovation and Technological Advancements: The field of smart parking is continuously evolving, presenting opportunities for innovation and technological advancements. Advancements in sensor technologies, data analytics, and connectivity solutions offer the potential for further enhancements in open parking lot management, creating opportunities for new solutions and improved efficiency.

The opportunity to enhance parking efficiency, optimize space utilization, and reduce traffic congestion is within reach through the deployment of smart parking technologies. These solutions also offer the chance to integrate with other mobility services, promote sustainability, and enable data-driven decision-making. Innovation and technological advancements continue to drive the development of smarter parking systems, opening doors for further improvements. By embracing these opportunities, stakeholders can collaborate to create seamless and efficient parking solutions that meet the needs of urban environments. By addressing the challenges and capitalizing on the opportunities, smart parking sensors, technologies, and applications have the potential to transform parking into a streamlined and sustainable experience. With continued research, innovation, and collaboration, manufacturers can create a future where parking becomes hassle-free, efficient, and environmentally friendly.

## 6. Conclusion

This article has identified a research gap in the utilization of smart parking sensors, technologies, and applications specifically tailored for open parking lots. Existing smart parking solutions are not well-suited for open parking lots due to the diverse environmental conditions and the significant associated costs. Economic considerations play a crucial role in selecting appropriate smart parking technologies for open parking lots, as immediate economic gains are not readily apparent. Among the existing smart parking technologies, the parking guidance system shows potential for providing an accurate count of available parking spaces in open parking lots. Additionally, machine vision technology, which utilizes visual cameras to obtain real-time parking occupancy information, proves to be a financially viable option for open parking lots. However, the use of visual cameras is subject to compliance with country-specific regulations, which should be carefully considered. It is important to note that there is no single technology that can be universally considered ideal for parking occupancy detection. Depending on the type and size of the parking lot, different combinations of smart parking technologies and sensors may be required to achieve efficient and financially feasible parking occupancy detection. Furthermore, to enhance parking efficiency, the provision of navigational directions to vacant parking spaces is crucial. Therefore, further research in the areas of deep learning and multi-agent systems can be instrumental in developing solutions that provide real-time parking occupancy information and navigational directions to available parking spaces in open parking lots. Addressing the challenge of efficient parking in open parking lots requires a multidisciplinary approach and the integration of advanced technologies. By exploring innovative methods and investing in research and development, it is possible to optimize parking efficiency and improve the overall parking experience in open parking lots.

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