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A review of smart parking systems

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Abstract

Conventional parking methods often result in inefficiencies, such as traffic congestion caused by drivers searching for available spots and inadequate revenue management for parking operators. Smart parking systems (SPS) aim to address these challenges by offering real-time information on parking availability, optimizing parking space utilization, and providing convenient payment options. This study seeks to comprehensively examine the academic research conducted on SPS to contribute to a deeper understanding of the current research landscape in this field. The research involved an extensive analysis of 124 published research papers, journals, and articles and revealed an intriguing trend: the proliferation of IoT-based SPS in urban settings is revolutionizing decision-making processes and elevating user experiences. Among the diverse range of SPS options, wireless sensor networks have emerged as a popular choice, as they not only eliminate the hassle of extensive wiring but also significantly reduce deployment expenses. Computer vision or image processing systems for vehicle detection require fewer sensors but come with substantial installation costs due to the necessity of a camera network. Conversely, SPSs based on vehicular ad hoc networks are experiencing slower adoption rates, mainly due to the high costs associated with installation and the requirement of on-board units in vehicles. The findings of this study will help researchers identify areas that require further investigation and city planners integrate smart parking systems into their overall smart city initiatives.

Keywords: Smart parking system, Internet of Things, Sensor network, Parking occupancy prediction, E-parking.

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1. Introduction

Despite the apparent simplicity of finding a parking space, it presents significant challenges that require substantial time, patience, and attention. Research findings reveal that in densely congested traffic zones, 30 to 50 percent of drivers spend an inordinate amount of time (3.5 to 14 minutes) in the pursuit of unoccupied parking spaces (Gallivan, 2011), which leads to driver frustration, traffic congestion, and an increase in air pollution. Studies have revealed that drivers who have access to parking availability information are 45% more likely to make successful parking decisions upon reaching their destination than those without such information (Wilbur-Smith Associates, 2009; Khan et al., 2022). Additionally, accelerating and cruising around parking lots contribute significantly to air pollution by generating a high volume of emissions (Frey et al., 2012; Khan et al., 2022a).

The global impact of technological innovations over the past decade cannot be underestimated. Entire living spaces are being shaped in profound ways by continuous advancements such as the Internet of Things (IoT), machine learning, big data, artificial intelligence (AI), and others. This transformation is particularly noticeable in the realm of parking, where the adoption of digital solutions is paving the way for the emergence of smart cities (Channamallu et al., 2023). The growing recognition of the limitations inherent in traditional parking lots, which struggle to adapt to population growth and traffic demands, is driving the ongoing expansion of intelligent parking solutions (Huang et al., 2022; Khan et al., 2023). According to a report by Research and Markets in 2023, the global smart parking market is projected to experience a compound growth rate of 18.47% annually from 2022 to 2030, reaching a market value of USD 21 billion by the end of the forecast period (Research and Markets, 2023).

Smart parking systems (SPS) have evolved over time to address the growing challenges associated with conventional parking management. Initially, basic parking meters and mechanical ticketing systems were introduced to regulate parking spaces, marking a significant milestone in the history of parking management in the 1930s (Shoup, 2011; Patel et al., 2023a). These meters facilitated time-based parking and fee collection, providing a regulated system for parking spaces (Bosch, 2013). In the 1980s, electronic parking meters emerged, bringing automated fee collection and improved enforcement capabilities (DeSouza, 2011; Apurva et al., 2023). The late 20th century witnessed the introduction of sensor technologies, leading to the development of sensor-based parking systems that provided real-time data on parking space availability (Bhagwat et al., 2007; Khan et al., 20233a). The integration of wireless communication technologies, such as Wi-Fi and cellular networks, enabled the transmission of parking data to drivers in real-time, with the advent of mobile applications offering parking information, navigation, and reservation options (Bastani et al., 2016; Patel et al., 2023). IoT-based architectures revolutionized SPS by facilitating seamless communication between sensors, devices, and infrastructure, enhancing data collection and management capabilities (Subramanya et al., 2022). The utilization of data analytics and AI techniques in SPS has gained prominence, enabling advanced parking optimization, predictive analytics, and personalized services for drivers (Khan et al., 2022b; Patel et al., 2022).

1.1. Benefits and Challenges of Digital Parking Systems

In a systematic literature review conducted by Yousafzai et al. (2019), SPSs were found to yield substantial benefits, including reduced traffic congestion, improved parking availability, increased revenue generation, and an enhanced user experience. These findings were corroborated by another survey on smart parking solutions conducted by Alamri et al. (2017), which highlighted advantages such as decreased search time for parking spaces, lower carbon emissions, improved revenue management, and enhanced driver convenience. Comparative studies further demonstrated the positive impacts of smart parking, including reduced traffic congestion, optimized parking space utilization, and enhanced traffic flow management (Loureiro et al., 2018; Patel et al., 2022a). Several studies utilized agent-based simulations to evaluate the effects of SPS on urban mobility, revealing advantages such as reduced travel time, improved parking availability and eased traffic congestion (Filho et al., 2018; Patel et al., 2023c). Despite the progress and deployment of SPS in various cities, however, there were reportedly multiple considerations regarding security, cost, implementation, and performance. One major concern was the lack of people's awareness and acceptance of the technology, as some individuals either rejected its use or failed to adhere to the prescribed procedures (Etminani-Ghasrodashti et al., 2022). Technical challenges plagued the dependability and integrity of the system, with potential vulnerabilities like wireless signal interceptions and routing protocol

attacks that could compromise sensitive data (Juliadotter, 2016; Patel et al., 2023b). Significant concerns were also raised regarding the high implementation costs and the impact of weather conditions on the infrastructure of the parking system, particularly the sensors (Patil et al., 2013; Etminani-Ghasrodashti et al., 2023).

1.2. Existing review studies in literature

The field of smart parking has garnered considerable interest in recent decades due to its numerous advantages. Researchers have actively engaged in addressing the challenges associated with SPS and devising innovative solutions. The existing literature encompasses a range of surveys and studies dedicated to smart parking, each with its own strengths and limitations. For instance, Chandrahasan et al. (2016) conducted a survey on reservations in parking lots, offering examples and explanations of reservation techniques; however, their survey lacked a comprehensive approach. Similarly, Revathi and Dhulipala (2012) presented a survey on the topic but omitted examples from the literature. Lin et al. (2017) concentrated on the evolution and development of smart parking, summarizing methodologies and common objectives. Kaur and Malhotra (2018) conducted a comprehensive review of various SPSs yet omitted a detailed examination of the system's architecture. Barriga et al. (2019) identified frequently utilized components in SPS and highlighted usage trends.

This research paper strives to address the limitations identified in prior studies, which often lacked a comprehensive approach and omitted essential examples. Instead, it endeavours to offer a comprehensive and holistic perspective on the subject of SPS. The ultimate goal is to contribute to a deeper understanding of the topic by consolidating and analysing the literature on various types of SPS that have been developed and delving into multiple aspects of them. The insights presented in this research will serve as a valuable reference for researchers in the field, and the findings will enable informed decision-making during the development process. The research also contributes to the broader Intelligent Transport Systems (ITS) framework by optimizing urban mobility and enhancing transportation efficiency.

2. Methodology

In order to accomplish the objectives of this study, an initial search was conducted across a range of databases including Google Scholar, IEEE Xplore, Springer, ProQuest, Science Direct, Scopus, and Web of Science to familiarize ourselves with the existing literature pertaining to the subject matter. Subsequently, we employed various combinations of keywords to gather conference proceedings, journals, and technical papers published after 2005 that focused on predicting parking availability. The 487 papers that were initially identified were subjected to further scrutiny to extract 198 peer-reviewed studies, and an additional round of examination was conducted to extract the studies that developed an SPS. Following a meticulous review process, a total of 124 pertinent studies were extracted and comprehensively examined. This analysis allowed us to draw well-informed conclusions regarding the current state of the field and advancements in smart parking, and synthesizing these findings provided us with valuable insights into the strengths, limitations, and potential areas for further improvement within this domain.

3. Smart Parking systems

An SPS consists of multiple interconnected elements that collaborate to enhance parking management and user satisfaction. These elements encompass occupancy sensors installed in parking spaces to detect vehicle presence, a communication network for seamless data transmission, a data management system for processing and analyzing information, and a user application that provides real-time updates (Revathi and Dhulipala, 2012).

3.1. Wireless Sensor Network (WSN) based SPS

Tang et al. (2006) presented a parking management system that utilized WSN by strategically placing wireless sensors in parking areas to detect and monitor parking lot occupancy. The collected sensor data was regularly transmitted to a database, enabling a variety of management functions, including locating vacant parking spaces, ensuring security, and generating statistical reports. Chinrungrueng et al. (2007) introduced an SPS that used optical

WSN to inform users of available parking spaces and provide directions to them. Optical WSNs also offered ease of installation and maintenance while providing even better accuracy in detecting occupancy. In another study by Yan et al. (2011), vehicles were equipped with short-range wireless transceivers and simple processors, while the parking lot infrastructure was equipped with wireless transceivers that transmitted parking and reservation information, and a control computer maintained a map of available spots. Drivers received messages on their terminals and could only reserve a parking space when they were in close proximity to the parking lot.

Yang et al. (2012) presented a prototype of a WSN-based SPS that consisted of WSN nodes, a central web server, a user interface based on a mobile phone application, and an embedded web server. Its purpose was to enable users to locate free parking spaces and access real-time information on parking availability. The data from the parking lot was transmitted to an embedded web server and then to a central web server, which users could access via a smartphone application. Patil et al. (2013) developed a modified SPS that allowed for real-time monitoring of parking lot occupancy by integrating WSN and RFID technology. ZigBee communication technology was utilized to facilitate wireless communication among the sensor nodes. Grodi et al. (2016) designed a WSN system for vehicle occupancy detection that provided real-time updates on parking lot availability to users through a smartphone application. Cynthia et al. (2018) introduced an IoT-based SPS that they integrated with an application-based user interface. Infrared sensors detected parking lot occupancy, and the collected data was transmitted to a cloud platform. Users could access the data through a mobile application and find the nearest available parking space that would accommodate a vehicle the size of theirs.

3.2. Image Processing-based SPS

Dharmareddy et al. (2013) implemented an SPS that utilized webcams and intelligent image processing to detect vehicle occupancy in parking lots. The captured imagery was processed and uploaded to a web server, and users were able to check the occupancy/vacancy of parking spaces via a web-based application or at the entrance gate, where the information was displayed on an LCD screen. Parking lots could be conveniently booked through SMS, which transmitted the reservation through the system's controller via a GSM module. Bura et al. (2018) proposed a platform that utilized camera networks, fog computing techniques, and advanced deep learning algorithms. The system was equipped with motorized camera heads and zoom lenses to facilitate efficient vehicle tracking and capture license plate images to calculate fees and enhance security. Ruili et al. (2018) developed an SPS that utilized AI image processing techniques to suggest parking places based on factors such as fees and the proximity of the parking to the user’s location. Ultrasonic sensors were used to detect parking lot occupancy, while cameras were employed for license plate recognition, enabling billing, and enhancing vehicle security. Safi et al. (2017) created a cloud based SPS, using IoT technologies, that provided a parking reservation service and incorporated RFID tags to ensure that only authorized individuals could access the parking lot. Additionally, the system enhanced vehicle security through license plate recognition technology and could detect oversized and overweight vehicles, preventing their entry into the parking area.

3.3. Vehicular Ad Hoc Network (VANET)-based SPS

Lu et al. (2009) introduced an SPS that was based on vehicle-to-vehicle communication and offered navigation services with real-time parking information, intelligent anti-theft protection, and the dissemination of parking information specifically designed for large parking lots. With their system, the entire parking lot could be efficiently managed by employing roadside units that utilized VANET technology. Sauras-Perez et al. (2014) proposed an E-parking concept that incorporated an on-board unit installed in vehicles that could identify and reserve preferred parking spaces. The system also provided value-added services to partially cover operational expenses and explore potential business opportunities. Geng and Cassandras (2012) presented an SPS that focused on urban areas. Their system offered parking space assignment and reservation services, along with parking lot suggestions based on factors like proximity to the destination and parking fees. Notable features of this SPS included a guaranteed reservation, communication between the infrastructure and vehicles, and parking lot detection.

3.4. Wired Network-based SPS

In research conducted by Sai Pavan et al. (2013), an SPS was introduced that utilized loop detectors as sensors to detect vehicles in parking lots, and the data collected was used to display the real-time occupancy status of the parking lot on an LCD monitor. This SPS design was adaptable and could be successfully implemented in various types of parking lots, including both closed and open spaces.

3.5. Other SPS

Khanna et al. (2016) conducted a study that introduced a smart parking solution that incorporated an IoT-based cloud platform. The system utilized IoT modules on-site to monitor and identify real-time availability of parking spaces. Users could conveniently check the status of parking lots and reserve a parking space through a smartphone application. Atif et al. (2016) implemented an IoT, and multi-agent system based SPS that developed a dynamic pricing structure for management who wanted to rent out their parking spaces, directed drivers to available parking spaces, and provided real-time data on vacant parking lots. Chatzigiannakis et al. (2016) proposed an IoT-based SPS that prioritized privacy protection. The system utilized elliptic curve cryptography instead of conventional public key cryptography, which made it suitable for devices with limited computational resources. Additionally, the system incorporated zero-knowledge proofs to further enhance privacy protection. Mukadam et al. (2020) presented an SPS based on smart vehicle presence sensors and IoT. The smart sensors, consisting of a sensor, single-board computer, battery pack, beeper, and LED indicator, detected the occupancy status of parking lots, and a monitoring center, along with the smart vehicle presence sensors and a smartphone application, monitored, controlled, and processed the collected data.

Luque-Vega et al. (2020) developed an SPS that incorporated IoT technology to aid drivers in locating the closest available parking spaces, provide real-time updates on traffic congestion, and suggest alternate routes to the SPS facility. Fog computing techniques were employed to enhance data transmission and processing efficiency, minimizing the volume of data needed for cloud-based analysis. Mathur et al. (2010) conducted a study that used vehicles equipped with GPS receivers and ultrasonic rangefinders to determine parking spot occupancy. The data collected from these vehicles was gathered and combined at a central server to generate a map showing parking availability. The disadvantage of this system, however, was that all the users were presented with the same information, which led to multiple cars converging on spaces that were already occupied and traffic becoming congested if the demand for parking exceeded the supply. Lan et al. (2014) proposed a system that aimed to detect real-time parking lot availability using crowdsourcing and embedded smartphone sensors. The system tracked the driver's path using a waist-mounted position dead reckoning method and employed a map-matching algorithm to correct directional errors in indoor environments. Salpietro et al. (2015) described an SPS with a mobile application-based user interface that utilized embedded sensors in smartphones and Bluetooth connectivity. Once the vehicle was parked, the system transmitted information to a remote server through a network and utilized Wi-Fi for device connectivity.

4. Discussion

The existing literature presents various approaches to SPS, based on technologies such as WSN, image processing, VANET, wired networks, and other innovative methods. Each approach has its own advantages and limitations, and the choice of technology depends on factors such as accuracy, cost, scalability, and ease of implementation. Numerous research studies have illustrated the effectiveness of IoT-based SPS in enhancing parking management and improving the user experience. These systems leverage various IoT technologies, including cloud platforms, sensors, smartphone applications, and advanced algorithms, to deliver real-time information about parking space availability, enable reservation services, and implement dynamic pricing strategies. Measures for privacy protection, vehicle security, and integration with navigation systems are also incorporated into these systems.

WSN-based SPS shows promising results in monitoring parking lot occupancy in real time and providing up-to-date information on available parking spaces. Studies explored various aspects of WSN-based SPS to accurately determine the occupancy status of each parking spot, and alternative solutions such as optical WSNs and secure wireless networks were proposed, offering comparable or even superior accuracy in occupancy detection compared

to traditional loop detectors. WSNs also provide real-time updates on parking availability, enabling drivers to find vacant parking spaces efficiently; however, challenges such as sensor accuracy, network reliability, and scalability need to be considered. Integrating WSN technology with mobile applications and web servers facilitates seamless access to parking information, enhancing user convenience, and offering benefits such as easy installation and maintenance, precise detection, and real-time updates. Overall, WSN-based SPS presents a viable solution for efficient parking management, as it provides accurate information on parking lot occupancy and helps drivers locate available parking spaces in real-time.

Image processing based SPS leverages cameras and image recognition techniques to detect parking lot occupancy. This approach is highly accurate and has other attractive features such as number plate recognition for billing and enhanced security. The disadvantages of the system are that it requires a larger initial investment due to the cost of the cameras and the processing infrastructure, and the image processing algorithms have to be capable of handling various lighting conditions, occlusions, and camera angles to ensure reliable results.

Intelligent image processing techniques integrated into SPS have also proved effective in enhancing parking management. Studies demonstrated the use of distributed camera networks, along with advanced deep learning algorithms, to accurately detect parking lot occupancy, recognize number plates, and enable real-time monitoring, fee calculation, and improved security. Additionally, the integration of fog computing techniques optimizes data processing and reduces the reliance on extensive cloud-based analysis.

VANET-based SPS utilizes vehicle-to-vehicle communication to provide real-time parking navigation services and disseminate parking information. This approach is particularly suitable for large parking lots and urban areas. VANET technology allows for efficient management of parking lots, as vehicles communicate with each other and the infrastructure; however, the deployment of the VANET infrastructure and the coordination of communication protocols pose implementation challenges.

Wired network based SPS rely on loop detectors or other wired sensors to detect vehicles in parking lots. This approach provides real-time occupancy information that can be displayed on LCD monitors or other user interfaces. Wired networks offer reliable communication and are less susceptible to interference than wireless networks; however, the installation of wired infrastructure can be more complex and costly, especially in existing parking lots.

5. Conclusion

SPSs have undergone significant development and have embraced a variety of approaches and technological advancements to accurately detect real-time parking occupancy and efficiently manage parking spaces. The integration of IoT technology has facilitated the monitoring and identification of available parking spots, allowing users to conveniently access the information through smartphone applications, and advancements in sensor technology and data processing have improved their effectiveness and reliability. Privacy concerns have been addressed through the utilization of encryption techniques and protocols that protect user privacy. The widespread adoption of IoT-based SPSs in urban environments is attributed to their data-driven decision-making capabilities and their ability to enhance the user experience. WSN is a popular choice for SPS implementation as it offers the advantage of wireless connectivity, reducing the need for extensive wiring and lowering overall deployment costs. Computer vision or image processing systems used for vehicle detection require fewer sensors but entail significant installation expenses due to the need for camera networks. Once installed, however, they generally require less maintenance. SPSs based on VANET have a low adoption rate, primarily due to their high installation costs and the requirement of on-board units in vehicles.

In conclusion, various studies have explored the implementation of SPS and have introduced innovative approaches to address the challenges of parking space availability and management. This research will serve as a valuable resource for researchers, academicians in the field of IoT, smart cities, the transportation sector, and urban planners, as it provides a foundation for further exploration and development of new concepts, technologies, and methodologies related to smart parking and IoT-based solutions.

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