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NAVIGATING THE FUTURE: UNDERSTANDING THE ESSENTIAL COMPONENTS FOR SUCCESSFUL SMART PARKING SOLUTIONS

ISRAA **M.** AL ABUDY* and NIDHAL **K.** EL ABBADI **

*College of Computer Science and Mathematics Engineering, University of Kufa, Najaf -Iraq
**College of Computer Techniques Engineering, University of Al Musaqbal , Babylon -Iraq

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ABSTRACT

In an era when there is increasing talk about the rapid growth in technology, it has become necessary to advance the service requirements of our daily lives, and the first thing we face is traffic jams and time spent searching for safe parking spaces. The smart parking system is a promising solution to face many of the problems that accompany large cities, where lack of work is considered one of the factors that cause pollution and the difficulty of movement due to congestion, which has become one of the main obstacles facing the community. The common way to find a parking space is the traditional way as the driver usually finds a place in the city through his periodic experience, searching, or luck. This process requires time and effort and may result in the worst-case scenario if the driver is driving in a city with high traffic especially at peak hours. Smart parking solutions are characterized by a specific architecture (such as cameras, sensors, communication protocols, and software solutions). But despite the limitations of these components, they constitute a smart parking solution. This paper discusses the most used types of components which guides the commuters to decide on the selection of component types to implement a smart parking solution.

KEYWORDS: Intelligent parking management, Intelligent Traffic Management in Smart Cities, Parking datasets, Parking optimization, Smart parking systems, Vehicle detection techniques.

1. INTRODUCTION

In recent years, rapid urbanization and the exponential growth in the number of vehicles have posed significant challenges to urban mobility, with parking management emerging as a critical concern for both drivers and city authorities [1]. The incessant search for parking spaces often leads to traffic congestion, wast fuel, and increase greenhouse gas emissions, necessitating the exploration of innovative solutions to optimize parking utilization. In response to this pressing issue, the development of smart parking systems has garnered considerable attention as a promising avenue to revolutionize the urban parking landscape.

Smart parking systems represent an integration of cutting-edge technologies, data analytics, and intelligent decision-making to efficiently manage parking spaces and improve the overall parking experience for drivers [2]. The incorporation of Internet of Things (IoT) devices and advanced sensor networks enable real-time data collection, facilitating the monitoring of parking space availability and guiding drivers to vacant spots [3]. Machine learning algorithms further enhance the systems' ability to predict parking demand patterns and optimize resource allocation in congested urban areas [4].

While the benefits of smart parking systems are evident, their implementation comes with its own set of challenges and limitations. Issues such as high infrastructure costs, interoperability challenges, and data privacy concerns have been observed as potential roadblocks to widespread adoption [5]. By understanding these challenges and learning from past case studies, policymakers and technology developers can devise strategies to overcome barriers and encourage the integration of smart parking solutions into existing urban infrastructures [6].

Through an in-depth analysis of the latest advancements, case studies, and success stories, this review paper aims to provide valuable insights for researchers, urban planners, and policymakers. By exploring the prospects and emerging innovations in smart parking technology, we hope to contribute to the ongoing

israam.alabudy@uokufa.edu.iq
nidhal.abass@fulbrightmail.org

discourse on optimizing urban mobility and creating more sustainable and livable cities.

The paper is organized as follows: In section two, Related works have been delved into that have informed the development of smart parking systems. Section three emphasizes the significance of efficient parking management in urban environments. While the fourth section discussed current parking problems in general, followed by an exploration of the challenges faced in this domain in section five. Section six introduces prominent public datasets utilized by researchers for smart parking studies. The fundamental techniques employed in smart parking systems are elucidated in section seven, while section eight introduces performance metrics used to evaluate the effectiveness of these systems. Ultimately, in section nine, draw the paper to a conclusion, summarizing the key findings and outlining potential future directions for smart parking research.

2. RELATED WORK

(Ananth, P) presented in a research paper an intelligent parking system based on IoT technologies that uses a microcontroller with sensors connected to the cloud. The system includes smart slots, RFID entry/exit, Number Plate Recognition (NPR) entry/exit, and strong vehicle entry rejection. Device efficiency was evaluated by measuring the robustness of RFID access and the accuracy of the NPR methodology, as well as the usability of the application. The RFID sensor robustness was 100 percent on average, while the NPR reached 95 percent accuracy with a detection period of less than a second. The application has a score of 4.2 stars for ease of use, and 90 percent of respondents like this app. The proposed system was found to be more efficient than cloud-based systems [7].

While the group of authors (Liu, B., et. al.) in their research came up with the results of a camera-based intelligent parking system that uses inverse perspective mapping (IPM) to provide an aerial view image of the parking lot, which is then processed to extract parking space information. The system also includes a guidance system to help drivers find available parking spaces. The system was simulated on a 3D scene based on the parking lot of Macau International Airport. In the experiment, the system achieved an accuracy rate of 97.03% and an average distance error of 8.59 pixels. The evaluation results show that the system is capable of providing accurate and useful information, especially in open space parking lots [8].

(Sahoo, B. B. P., et. al.) presented the experimental results of a CNN-based smart parking system designed to detect vacant and occupied parking spaces through CCTV cameras and provide feedback to passengers. The proposed approach is cost effective, saves time and delivers excellent results in terms of accuracy. The results showed positive results about the given system, and the experimental results were used for comparison with the desired system. The dataset used in the experiment follows the hyperparameter training method. The method is used to present experiments using three sets of experiments to show the desired results [9].

(Abu-Alsaad & H. A.) discusses the challenges faced in real-time smart parking and proposes a solution using machine learning and the Internet of Things. The authors used the YOLO model to detect objects in real time and pushed a predefined algorithm into a microcontroller to ensure the sensors worked. The data collected by the sensors is sent to the cloud database or Firebase database and can be accessed via an app. The paper did not present any specific results as it is a proposal to solve the smart parking problem [10].

The research review done by (Saleem, A. A., et. al.) of various research papers related to smart parking systems based on the Internet of Things. It offers different sensor-enhanced models, integrating cloud and mobile applications that result in a smart parking system that saves time, energy, fuel and thus carbon footprint. The paper highlights the challenges of finding vacant parking spaces in megacities and the benefits of using smart parking systems based on the Internet of Things. However, the paper did not present any specific findings of its own research [11].

The paper by (Acharya, D., et. al.) demonstrates a CPU-friendly pipeline for real-time image-based parking occupancy detection using deep learning. The authors use convolutional neural networks as feature extractors and an SVM binary classifier for parking occupancy detection. They create a small dataset from a PKLot dataset of 3,000 parking lot images and use it to train the classifier. The trained classifier is then used to perform parking occupancy detection on the Barry Street dataset. The authors report the accuracy that can be achieved by using different networks as feature extractors and reporting runtimes [12].

(Barriga, J. J, et. al.) presented a literature review of smart parking solutions from a technological perspective. The authors addressed the most commonly used component types such as sensors, communication protocols, and software solutions in smart parking solutions. The paper also highlights usage trends in the given analysis period and provides a guide for complementary component-type features that should be considered when implementing a smart parking solution. However, the paper did not provide any specific findings in terms of trials or outcomes [13].

(Bura, H., et. al.) evaluated the results of the trained models by using them to infer videos captured from different parking lots at different angles and conditions. Model efficiency is measured in terms of its accuracy. Confusion matrices taking null to be positive and occupied to be negative the proposed miniAlexNet in takes 15 seconds to classify 50 slots, while the specially designed model takes 50 x 7.11ms = 355.5ms to classify 50 slots [14].

(de Almeida, et. al.) presents a systematic review of existing work that uses publicly available image datasets to test computer vision-based approaches to parking management approaches. The authors surveyed and compared robust publicly available image datasets and proposed certain criteria to identify the parking lot image dataset as robust. They also reviewed, ranked, and compared recent business results using the surveyed datasets. The paper identified related gaps that require further research, such as requirements for dataset-independent approaches and appropriate methods for self-detection of parking space locations. Analysis of the datasets also revealed that some features that must have been present when developing new standards, such as the availability of video and image sequences taken in more diverse conditions, including night and snow, were not incorporated. However, the paper also notes that the testing procedure may have biased results or been unclear. The paper presents results in AUC-ROC and false negative rate (FNR)/false positive rate (FPR) [15].

Table 1 summarizes the findings from different research papers on smart parking systems. Each row represents a unique research paper, detailing the method used, an overview of the details of the study, the pros and cons of each method, and potential improvements that can be made in the future. The table provides a comprehensive overview of the latest developments in smart parking systems, highlighting the strengths and weaknesses of each approach and paving the way for future improvements.

Table (1) :-Comparative analysis of vehicle detection methods

Reference	Method	Details	Pros.	Cons.
Prithiviraj Ananth, 2021	IoT-based system with RFID, NPR, and cloud connection	Evaluated robustness of RFID and accuracy of NPR	High system efficiency and user satisfaction	Only measures RFID robustness and NPR accuracy
Bowie Liu , et al., 2023	Camera-based system with IPM	Used 3D scene for simulation	High accuracy, useful especially in open space lots	Only tested on one type of parking lot (Macau International Airport)
Hiba A. Abu-Alsaad ,2023	CNN-based system using CCTV	Compared the experimental results with desired ones	Cost-effective and time-saving	Performance measures not specified
Biren Bishnu Prasad Sahoo, et al., 2021	IoT and machine learning based system	A proposal using YOLO and microcontroller	Comprehensive use of latest technologies	Lack of practical results
Adil Ali Saleem, et al., 2020	Literature review on IoT-based smart parking	Focus on sensor-enhanced models	Highlights benefits of IoT-based systems	No specific findings
Debaditya Acharya, et al., 2020	Image-based system with CNN and SVM	Used a PKLot dataset for training	Demonstrated CPU-friendly pipeline	Limited to image-based detection
Jhonattan J. Barriga, et al., 2019	Literature review on smart parking solutions	Focus on component types	Comprehensive overview of smart parking technology	Lack of specific trial outcomes
Harshitha Bura, et al., 2018	Video-based inference	Efficiency measured in terms of accuracy	Detailed performance analysis	Limited to video-based detection

Paulo Ricardo of Lisbon de Almeida, et al.,2022	Literature review on image datasets	Comparison of image datasets for parking management	Identified gaps requiring further research	Biased testing procedure

3. THE IMPORTANCE OF PARKING

Smart parking systems can be tremendously important in crowded cities for a number of reasons:

1. Reducing Traffic Congestion: One of the primary causes of traffic congestion in urban areas is drivers looking for parking. By providing real-time information about available parking spaces, smart parking systems can help reduce the amount of time drivers spend circling the block in search of a spot [16].

2. Enhancing User Experience: With features like mobile apps for parking payments and availability checks, smart parking systems can significantly enhance the user experience [17].

3. Increasing Parking Efficiency: By maximizing the use of existing parking spaces, smart parking systems can increase parking efficiency. This can reduce the need for new parking lots and thus preserve valuable urban space for other, potentially more beneficial uses [18].

4. Reducing Carbon Emissions: By reducing the time spent looking for parking, smart parking systems can lower vehicle emissions and contribute to a cleaner, healthier urban environment [19].

5. Improving Public Safety: Smart parking systems can improve public safety by reducing the risk of accidents associated with frantic parking searches. They can also provide surveillance in parking areas, further contributing to safety [20].

6. Generating Revenue: For city administrations, smart parking systems can be an effective source of revenue. Dynamic pricing, which adjusts the cost of parking based on demand, can also be implemented to optimize revenue [21].

7. Enabling Better City Planning: The data collected by smart parking systems can be used for urban planning. By providing insights into parking behavior and patterns, it can help planners make informed decisions about where to add or reduce parking facilities [22].

8. Supporting the Growth of Smart Cities: Smart parking is an integral part of the smart city concept. By integrating with other smart city systems and technologies, it can contribute to creating more connected, efficient, and sustainable urban environments [23].

Today, cities are responsible for more than 75% of waste production, 80% of emissions, and 75% of energy utilization. With regard to Europe, road transportation produces about 20% of the total CO_2 emissions, out of which 40% is generated by urban mobility. It is estimated that vehicles cruising for free parking spaces cause 30% of the daily traffic congestion in an urban downtown area [24].

In summary, smart parking systems can contribute to solving some of the most pressing challenges in crowded cities, and they are therefore of tremendous importance.

4. Problems Facing the Smart Car Parking System

1. Inaccuracy of Sensors: The sensors that detect whether a parking space is occupied or it is vacant may malfunction or be affected by several factors (like extreme weather conditions, dirt, calibration, maintenance, etc.), causing them to provide inaccurate information. This could lead to drivers being misinformed about the availability of parking spaces [21].

2. Cybersecurity Breaches: Given that smart parking systems rely heavily on data communication and storage, they are susceptible to cyber-attacks. Hackers could potentially gain unauthorized access to sensitive data or even disrupt the operation of the parking system [22].

3. Network Connectivity Issues: These systems often depend on constant network connectivity. Any disruptions or instability in the network could cause the system to function improperly or even fail, causing confusion or inconvenience for users [23].

4. Ineffective User Interface: If the mobile applications or other user interfaces associated with the system are not user-friendly or have technical issues, it can result in poor user experience. Users may find it difficult to locate or book available parking slots [22].

5. System Overload: If the system isn't designed to handle a large number of users or requests at once, it may overload and crash during peak usage times [23].

6. Poor Integration with Other Systems: Smart parking systems often need to integrate with other city systems or traffic management systems. If this integration is not smooth, it can lead to operational problems [21].

7. Vandalism: Physical components of the system like sensors or cameras may be subject to vandalism, which can cause them to stop working or provide inaccurate information [21].

8. Lack of Real-Time Updates: If the system doesn't update parking space availability in real-time, it can lead to situations where multiple drivers are directed to the same parking spot [23].

9. Legal and Regulatory Issues: If the system doesn't comply with all relevant laws and regulations, such as those related to data protection, it could lead to legal problems [22].

10. Reliance on Power: Since these systems rely on electricity to function, any power outages could result in system failure [23].

5. The Most Important Challenges Facing The System

1. Image Quality and Lighting Conditions: Cameras need to capture high-quality images to accurately detect whether a parking space is occupied or not. This becomes challenging in different lighting conditions such as at night, during heavy rain, fog, or snow [25].

2. Obstruction and Blind Spots: There can be areas in the parking lot that are not visible to the cameras due to obstructions or the positioning of the cameras. This can lead to inaccurate detection of parking space availability [21].

3. Camera Placement and Angles: Determining the ideal placement and angles for cameras to cover the maximum area with minimum devices can be a major challenge [25].

4. Real-time Processing: Processing and interpreting the image data from cameras in real time can be computationally intensive and can require substantial processing power and sophisticated algorithms [26]

5. Privacy Concerns: As mentioned earlier, the use of cameras for monitoring parking spaces can lead to privacy concerns from the public, particularly if the cameras are capturing images of individuals or private vehicles [27].

6. Maintenance and Vandalism: Cameras, being external devices, are exposed to environmental conditions and potential vandalism. This can result in regular maintenance requirements and potential downtime [27].

7. Integration with Other Systems: The data from cameras needs to be seamlessly integrated with other systems such as parking management software or mobile apps. Ensuring this interoperability can be challenging [26] [25].

8. Object Recognition: The cameras need to accurately recognize vehicles of different types and sizes. This can be challenging as the system needs to differentiate a vehicle from other objects that might be in the parking space [25].

9. Weather Resistance: Cameras placed outdoors must be resistant to various weather conditions, such as rain, wind, or extreme temperatures. Ensuring this durability can be challenging [27].

10. Data Storage: Storing the large amounts of video data captured by cameras can be a challenge. This also includes considerations around data security and privacy [25].

11. Network Dependability: For real-time data transmission and processing, a reliable and fast network connection is vital. Network connectivity issues can pose significant challenges [25].

6. DATASETS

Datasets play an essential role in developing and testing smart parking systems. They can be used to train machine learning algorithms for vehicle detection and parking space identification, and to evaluate the performance of these algorithms. There are several types of datasets that can be used in smart parking systems, including:

6.1 NDIS_Park Dataset

NDIS_Park Dataset is a small, manually annotated dataset for counting cars in parking lots, was created by the NDIS Lab in Australia. consisting of about 250 images. This dataset is challenging and describes most of the problematic situations that we can find in a real scenario: seven different cameras capture the images under various weather conditions and viewing angles. Another challenging aspect is the presence of partial occlusion patterns in many scenes such as obstacles (trees, lampposts, other cars) and shadowed cars. Furthermore, it is worth noting that images are taken during the day and the night, showing utterly different lighting conditions and that, unlike most counting datasets, the NDISPark dataset is precisely annotated with instance segmentation labels, allowing us to generate accurate ground truth density maps for the counting task since the size of the vehicles is well-known [30].

6.2 PKLot Dataset

The PKLot dataset is a substantial dataset for parking lot classification, was developed by the PUCPR University in Brazil. With over 695,899 images of vacant and filled parking spaces, this dataset was amassed from two distinct parking lots over a month. Given that the images were taken under varying weather conditions and at different times of the day, it is an optimal choice for formulating and evaluating algorithms designed to deal with a multitude of real-world conditions [31].

6.3 CNRPark Dataset

CNRPark Dataset was developed by the National Research Council in Italy. is a benchmark of about 14,527 images of 250 parking spaces collected in different days, from 2 distinct cameras, which were placed to have different perspectives and angles of view, various light conditions and several occlusion patterns, built a mask for each parking space in order to segment the original screenshots in several patches, one for each parking space. Each of these patches is a square of size proportional to the distance from the camera, the nearest are bigger then the farthest [32].

6.4 CNRPark+EXT Dataset

CNRPark+EXT Dataset is also developed by the National Research Council in Italy a dataset of roughly 144,965 labeled images of vacant and occupied parking spaces, built on a parking lot of 164 parking spaces. CNRPark-EXT includes and significantly extends CNRPark [32].

6.5 PLD (Parking Lot Dataset)

The Parking Lot Dataset (PLD) was created by the Institute of Industrial Technology in South Korea. boasts a diversity of images from parking lots with different configurations, vehicle types, and a range of lighting and weather conditions. The images in this dataset are annotated with the locations of the parking spaces and their occupancy status [33].

These datasets can be used to train machine learning models for parking spot detection and occupancy detection tasks. By using these datasets, researchers can evaluate the effectiveness of their models in different scenarios, including varying weather conditions, times of day, and parking lot configurations. Fig.1 presents a sample for each data set mentioned

Table 2 provides comprehensive comparison of various parking lot image datasets sourced from different universities and institutes across the globe. Key characteristics such as the source of the dataset, year of publication, total images, camera resolution, image format, labeled spaces, weather and lighting conditions, camera perspectives, types of parking lots, and the annotation method used in each dataset are detailed. This comparison allows users to understand the scope and applicability of each dataset, including aspects like diversity of lighting and weather conditions, variety of parking lots, and the quality and richness of the image data and annotations.

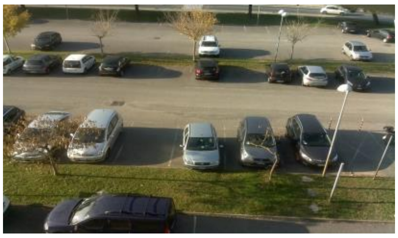
Table (2):- Comparison Of Various Parkinking Lot Image Datasets

Feature	NDIS_Park	PKLot	CNRPark	CNRPark-EXT	PLds
Source	University of Rome (Italy)	Federal University of Parana (Brazil)	University of Rome (Italy)	University of Rome (Italy)	University of Applied Sciences (Germany)
Year of Publication	2021	2015	2015	2016	2021
Total Images	259	695,899	14,527	144,965	12,417
Camera Resolution	2400*1808	640x480	640x480	720x576	1280x720
Image Format	RGB	RGB	RGB	RGB	RGB
Labeled Spaces	259	12,417	144	369	2,000
Weather Conditions	Sunny, cloudy, rainy, snowy, foggy	Sunny, cloudy, rainy	Sunny, overcast, low-light	Sunny, overcast, low-light	Sunny, cloudy, rainy, snowy, foggy
Lighting Conditions	Daytime, nighttime	Daytime, nighttime	Daytime	Daytime	Daytime, nighttime
Camera Perspectives	Multiple	Multiple	Single	Single	Multiple
Types of Parking Lots	Open-air	Open-air, multi-story	Open-air	Open-air	Open-air, underground, multi-story
Annotation	Each image is manually labeled with pixel-wise masks and bounding boxes localizing vehicle	Bounding box, occupancy status	Bounding box, occupancy status	Bounding box, occupancy status	Bounding box, occupancy status


NDIS_Park


PKLot


CNRPark


CNRPark-EXT


PLds

Fig.(1):-illustrates five key datasets - NDIS_Park, PKLot, CNRPark, CNRPark-EXT, and PLds.

These datasets, each featuring unique characteristics, serve as crucial resources for developing and refining intelligent parking systems. They contribute diverse scenarios for training machine learning models, testing algorithm performance, and enhancing the accuracy and efficiency of smart parking solutions.

7. Techiques Used Worldwide

There are three main technologies used in smart parking systems include: sensor technology, computer vision (image processing), and Internet of Things technology. Below is a detailed explanation of each technique:

7.1 Sensor Technology

These systems deploy sensors such as ultrasonic, magnetic or infrared throughout each parking space. Sensors are able to detect the presence or absence of vehicles. Accurately detects parking space availability and updates data in real time. But they have high initial installation costs as one sensor per spot is required and are subject to physical damage, and sometimes the sensors can give false readings due to external environmental factors. Most sensor systems operate on simple threshold-based algorithms for detection. If the sensor reading exceeds a certain value, the slot is considered occupied. [34].

7.2 Computer vision (image processing)

These systems use cameras to take pictures of the parking lot and use image processing algorithms to determine which spaces are empty and occupied. Advantages include covering a large area with fewer devices than sensor systems, and can include additional features such as Automatic Number Plate Recognition (ANPR). Conversely, factors such as lighting conditions, camera angle, and weather can affect the accuracy of the system. The system requires high computational resources for image processing. Technologies such as convolutional neural networks (CNN), inverse perspective mapping (IPM), and support vector machine (SVM) classifiers are used [10].

7.3 Internet of Things

The interconnection of various devices such as sensors, cameras, and gateways via the Internet. The data from these devices is processed and analyzed in real time to provide parking information. IoT technology provides a comprehensive solution that combines the advantages of sensor and camera systems. It can be integrated with mobile applications for user convenience. But it requires a strong network infrastructure and a high-speed internet connection. System security can be a concern. Machine learning and deep learning algorithms such as YOLO (You Only Look Once) are used to detect objects in these systems [35]. The table 3 provides a detailed comparative analysis of various smart car parking technologies based on their method of operation, strengths, weaknesses, challenges encountered in implementation, and the algorithms typically associated with each. The technologies analyzed include Sensor Technology, Computer Vision, and IoT Technology.

Table(3):-Comparative Analysis Of Smart Car Parking Techiques

Technology	Method	Strengths	Weaknesses	Challenges	Algorithms
Sensor Technology	Use of sensors for occupancy detection	High accuracy, Real-time updates	High cost, Prone to physical damage	High installation & maintenance cost, Ensuring accuracy	Threshold-based detection
Computer Vision	Use of cameras and image processing	Large area coverage, Additional functionalities	Affected by environmental factors, High computational resources	Handling environmental conditions, High computational demand	CNN, IPM, SVM
IoT Technology	Interconnection of various devices via the Internet	Comprehensive solution, Integration with mobile apps	Requires robust network, Security concerns	Network security, Data handling, System interoperability	Machine learning, Deep learning (e.g., YOLO)

8. PERFORMANCE METRICS

In smart parking systems, several performance metrics can be used to evaluate their functionality, efficiency, and reliability. Such as determining the status of parking spaces in smart parking systems – occupied or vacant These performance metrics often take into account various components and technologies used within the system, such as sensors, Internet of Things (IoT) devices, image processing algorithms, and machine learning models [37]. Here are some performance metrics:

8.1 Accuracy

One of the clearest and most common metrics used in smart parking systems is accuracy. This is especially important for systems that use sensors, computer vision, or machine learning to detect if parking spaces are occupied or vacant. Accuracy is calculated as the number of valid detections (both occupied and vacant) divided by the total predictions made by the system [36].

This arithmetic formula of accuracy can be represented as follows:

Accuracy = (Number of correct predictions / Total number of predictions) * 100%

Applying this in the context of a smart parking system, 'Number of correct predictions' encompasses both True Positives (TP - parking spots correctly identified as occupied) and True Negatives (TN - parking spots correctly identified as vacant). 'Total number of predictions' is the cumulative of True Positives (TP), True Negatives (TN), False Positives (FP - parking spots erroneously identified as occupied), and False Negatives (FN - parking spots incorrectly identified as vacant).
This can be redefined as:

$$\text{Accuracy} = ((TP + TN) / (TP + TN + FP + FN)) * 100\%$$

Expressed as a percentage, a higher accuracy suggests a more proficient system in correctly identifying the status of parking spots. In an ideal scenario, an accuracy of 100% would indicate a flawless system, although such precision is seldom attainable due to various uncertainties and imperfections in real-world data and prediction algorithms.

The range of the accuracy metric extends from 0 to 100% (or 0 to 1 when not expressed as a percentage). A target of 95% or higher is a reasonable standard for most smart parking applications. The extremes of the scale represent:

1. Lowest value (0% or 0): An indication that the system has not made any correct predictions. This undesirable outcome signifies that the system has failed to accurately identify the status of any parking spots.

2. Highest value (100% or 1): This implies that the system has correctly made all predictions. In the context of a smart parking system, it represents a flawless identification of all parking spots' status, making it the desired outcome.

Hence, a higher accuracy is desirable as it indicates a higher proportion of correct predictions, thereby denoting a more reliable and efficient system. However, high accuracy alone does not comprehensively evaluate the system's performance and must be coupled with other metrics such as precision, recall, and F1-score for a more holistic assessment.

8.2 The Speed of Detection

In a smart parking system is a measure of the time taken for the system to detect and report any change in the status of a parking spot (i.e., from occupied to vacant or vice versa). This metric is calculated by noting the time difference between the occurrence of the event (such as a vehicle vacating a parking spot) and the system's report of the same event [38].

The calculation can be illustrated as:

Speed of Detection = T2 - T1

where

T1= is the time of occurrence of the event, T2= is the time when the system reports the event.

The result is typically represented in units of time, such as seconds or milliseconds.

The 'Speed of Detection' metric's values are bounded by the limits of time.

1. Lowest Value: The theoretical lowest value is 0, indicating that the system detects and reports changes in parking space status instantly. However, this is practically unattainable due to physical and processing constraints.

2. Highest Value: The highest value is theoretically unbounded – it could take an inordinately long time for a system to detect and report a change in status if the system is inefficient or faulty or if other external factors are influencing its performance. However, in a functional system, this value would typically range within seconds or minutes.

The desired value for “Detection Speed” is a value ranging from (2-3) seconds up to (60) seconds where the shorter the detection time the better for the system, indicating a system that can quickly detect and report changes in parking space occupancy, resulting in Better user experience [8].

8.3 Reliability

In the sphere of smart parking systems, the reliability metric is a composite measure computed from multiple diverse factors [39]. Below is a breakdown of each component that contributes to this composite metric, along with how it is calculated:

1. Sensor Reliability: This measure can be computed as the ratio of accurate sensor readings to the total number of sensor readings. An accurate reading refers to the correct identification of a parking spot's occupancy status, i.e., occupied or vacant. For instance, if there are 100 sensor readings in total, and 95 among them are accurate, the sensor reliability would be 95/100 = 0.95 or 95%.

2. System Uptime: This pertains to the fraction of total elapsed time for which the system is functional, i.e., it is neither down for maintenance nor due to errors. As an example, if the system was operational for 23 hours out of a 24-hour day, the system uptime would be 23/24 = 0.958 or 95.8%.

3. Detection Strength: This parameter quantifies the system's ability to handle variations in conditions such as lighting, weather, and different vehicle types. It could be calculated as the ratio of accurate detections under varying conditions to the total number of detections under these conditions, yielding a percentage or ratio.

To amalgamate these three factors into a single reliability score, one could calculate the average. For example, if the sensor reliability is 95%, system uptime is 96%, and detection strength is 90%, the overall reliability would be (0.95 + 0.96 + 0.90) / 3 = 0.937 or 93.7%.

The minimum value of this combined reliability score would be 0 (or 0% when expressed as a percentage), indicating a system that never functions correctly. The maximum value would be 1 (or 100%), denoting a system that consistently functions perfectly under all conditions. Higher values are indicative of a more reliable system.

For the aforementioned reliability scale, it typically ranges from 0 to 1, where 0 represents the lowest value, and 1 the highest. Alternatively, it can also be expressed as percentages, spanning from 0% (the system never functions correctly) to 100% (the system always functions perfectly under all conditions). i.e.:

Lowest value (0 or 0%): This represents a completely unreliable system. This would imply that the sensors never provide accurate readings, the system is never operational, or it never correctly detects the occupancy of parking spots under various conditions.

Highest value (1 or 100%): This would signify a flawless system that never fails. It would mean that the sensors always provide accurate readings, the system is always operational, and it consistently identifies the status of parking spots correctly under all possible conditions.

8.4 Scalability

In the context of smart parking systems, scalability can be interpreted as the capability of the system to manage an increasing number of parking spaces without a significant decline in performance metrics, namely accuracy, speed, and reliability [40]. To measure scalability quantitatively, it is frequently evaluated in terms of performance metrics per unit of scale. For the purpose of this study, a unit of scale may be construed as a specific number of parking spaces (e.g., per 100 spaces). Accordingly, the performance of the system—using metrics such as accuracy, speed, and reliability—is measured at different scales (e.g., 100 spaces, 200 spaces, 300 spaces, etc.).

The scalability can be calculated using the following formula:

Scalability Index = (Performance at N spaces / Performance at baseline) / (N / Baseline)

Where

N= the number of parking spaces at which performance is evaluated, Performance= any of the metrics such as accuracy, speed, or reliability and, Baseline= denotes the number of parking spaces at which the system exhibits optimal performance.

Under ideal circumstances, the Scalability Index should approximate to 1, indicating that the system can uphold its performance as the number of parking spaces proliferates. A Scalability Index substantially lower than 1 suggests that the system's performance deteriorates more rapidly than the increment in parking spaces, thereby indicating inadequate scalability.

It is essential to note that real-world computation of scalability can be intricate, necessitating complex statistical analyses and the application of machine learning or other prediction methodologies to account for potential non-linear relationships and interactions among different system components. Consequently, the precise methods for quantifying scalability may differ depending on the specific system and context.

The Scalability Index in the proposed mathematical model is dimensionless and typically ranges from 0 to 1, or is expressed as a percentage (0% to 100%).

1. Maximum Value: The maximum value would be 1 (or 100%, when represented as a percentage), implying that the system exhibits perfect scalability and maintains its performance irrespective of the number of parking spaces it manages. This would be the optimal upper value, indicating that the system's performance is not impacted by scaling.

2. Minimum Value: The minimum value would be 0 (or 0%, when represented as a percentage), indicating that the system lacks scalability and its performance deteriorates as the number of parking spaces increases.

Thus, a higher scalability index, closer to 1 (or 100%), is indicative of better system scalability. However, achieving perfect scalability (1 or 100%) in real-world applications can be challenging due to various technical and practical limitations. Therefore, a scalability index that is closer to 1 (or 100%) is typically considered desirable.

8.4 Resource Consumption

This metric evaluates the efficiency of a system in terms of the resources it uses, a critical factor in the operation of a smart parking system, can be subcategorized into three primary constituents - such as power consumption for sensors and IoT devices, bandwidth usage for data transmission, and computational resources for processing detections and serving users. [41].

1. Power Consumption: This quantification can be achieved by measuring the energy expended by sensors, IoT devices, and servers over a specific period, typically represented in kilowatt-hours (kWh). For instance, if a sensor consumes 1 watt of power over 1000 hours of operation, it has expended 1 kWh of energy.

2. Bandwidth Usage: This signifies the volume of data transmitted over the network in a given time frame, typically quantified in gigabytes (GB) or terabytes (TB). Network monitoring tools can aid in tracking this metric.

3. Computational Resources: These are typically evaluated considering CPU usage, memory usage, and storage space utilized by the system for processing detections and serving users. System monitoring tools can measure these metrics, and they are usually reported as a percentage of usage or in units, such as gigabytes for memory and storage.

For an integrated measure of resource consumption, an index or score might be devised that takes all these factors into account. However, given the disparate nature of these aspects, their amalgamation into a single value may necessitate assumptions or weighting factors to prioritize certain types of resource consumption over others. The scale's limits for resource consumption would theoretically be zero at the lower end, although this is unattainable for an operational system. The upper limit would correspond to the total available resources, including power supply limits, total available bandwidth, and total available computational resources. Generally, lower resource consumption is desirable, signifying a more efficient system. However, the system's performance must be factored in - a low-resource-consuming system delivering subpar performance would not be beneficial. Thus, resource consumption and system performance often present a trade-off.

In terms of resource consumption:

Power Consumption: The lower limit is theoretically 0 kWh, which signifies no power consumption, an unfeasible scenario for an operational system. The upper limit is confined by the power supply capacity. Lower power consumption, indicative of greater energy efficiency, is generally preferable, emphasizing the desirability of the lower value.

Bandwidth Usage: The lower limit of zero represents no data transmission, again an improbable scenario for an operational system. The upper limit is dictated by the bandwidth capacity of the network. As with power consumption, a lower bandwidth usage, indicative of more efficient network resource usage, is generally preferable.

Computational Resources: This encompasses CPU usage, memory usage, and storage usage. For each, the lower limit is zero usage, which would signify a non-operational system. The upper limit would correspond to the total available CPU processing power, total memory, and total storage space. Lower values, indicative of a more efficient system, are typically better.

8.5 User Experience

The User Experience metric, while often more subjective and qualitative in nature compared to other technical measurements [42]. can also be rendered into quantifiable terms through several methods:

1. User Reviews and Ratings: The arithmetic mean of user ratings on a given scale, typically ranging from 1 to 5 or 1 to 10, can be computed. For instance, given 100 ratings in which 60 users rate the system at 5 out of 5, and 40 users provide a rating of 4 out of 5, the average rating can be calculated as (60*5 + 40*4) / 100 = 4.6 out of 5.

2. User Interface (UI) Speed and Intuitiveness: This facet, while more subjective and challenging to quantify, could be assessed through user testing sessions. These sessions could measure task completion time, the number of user errors, and the duration required for a new user to acclimate to the interface. Here, shorter durations and lower error rates denote a more intuitive and faster UI.

3. Meeting User Needs: Users could be surveyed regarding how well the system fulfills their requirements, using a numerical scale. The survey could encompass questions about the rapidity of parking space location, the utility of features like advanced booking, and overall user satisfaction with the system.

In these measures, lower values generally signify a poor user experience (e.g., slow interface, system not meeting user needs), while higher values denote a better user experience. However, given their basis in subjective human experiences and perceptions, these measurements must be interpreted contextually, acknowledging that room for improvement typically exists, even in the presence of high scores.

8.6 Cost Effectiveness

Cost Effectiveness serves as a metric that juxtaposes the costs incurred through the implementation of a system against the benefits it yields. Quantifying this measure can pose a challenge owing to the complexity and diversity of both costs and benefits [43].

To compute the Cost Effectiveness, the following approach can be employed:

1. Determination of Total Cost: This should encompass all the costs associated with the system. For an intelligent parking system, this would generally involve costs related to hardware (e.g., sensors), software development and licensing, installation, operation (such as electricity and data transmission costs), and maintenance.

2. Quantification of Benefits: Quantifying benefits can prove more challenging and may necessitate estimations. Within the context of a smart parking system, benefits could include time saved by drivers due to expedited parking space location, increased revenue resultant from more efficient parking space utilization, and user satisfaction enhancement potentially leading to repeat business or positive reviews.

3. Calculation of the Cost-Effectiveness Ratio: This ratio is obtained by dividing the total cost by the quantified benefits. A lower ratio implies a more cost-effective system, as this indicates a greater yield of benefits for each unit of cost.

4. Sensitivity Analysis: Given that the benefits aspect involves several estimations, it is advisable to conduct a sensitivity analysis. This will shed light on how fluctuations in these estimates could influence the cost-effectiveness ratio.

The values of this metric are typically positive real numbers. Although there is theoretically no upper limit, a lower value is preferable as it indicates enhanced cost-effectiveness of the system.

In terms of the limits of the Cost Effectiveness measurement scale:

Highest Value: In theory, there is no definitive maximum value for cost-effectiveness. This value could inflate to the extent of costs incurred to derive negligible or zero benefits. However, in practical scenarios, a high cost-effectiveness ratio is undesirable as it suggests that the costs are exorbitant relative to the benefits procured.

Lowest Value: The minimal possible value would be 0, implying that benefits are obtained at no cost. However, this is a theoretical extreme unlikely to be encountered in practical applications.

Desirable Value: A lower value is typically preferable, as this indicates that the cost is low relative to the benefits derived. Hence, a smaller cost-effectiveness ratio is desirable. It is also pertinent to note that context is key - different organizations or situations may exhibit different acceptable thresholds for cost-effectiveness.

In table 4 presents a comparison of different smart car parking techniques and their corresponding detection accuracy. These techniques incorporate various sensor types, video surveillance, image processing methods, and IoT-based solutions. Detection accuracy is represented as an approximate percentage range, which may vary based on the specific technique implementation, environmental conditions, and system setup. Please refer to the most recent and specific data for decision-making purposes. This comparison aims to provide an overview of the relative accuracy of different techniques used in smart car parking systems. [44].

Table(4):- Comparative Analysis Of Detection Accuracy For Various Smart Car Parking Techniques

Smart Car Parking Techniques	Detection Accuracy
Ultrasonic Sensors	85-95%
Infrared Sensors	80-90%
Magnetic Field Sensors	70-85%
Video Surveillance	90-95%
Image Processing Techniques	85-95%
Radio Frequency Identification (RFID)	95-100%
IoT-based Solutions	90-98%

9.CONCLUSIONS

The literature reviewed in this study emphasizes the pivotal role of:

9.1 Recognize the importance of vision-based vehicle detection techniques

The vital role that vision-based vehicle detection technologies play in the development of intelligent parking systems. These technologies are key to unlocking the future potential of efficient and intelligent parking management.

9.2 Evaluate the strengths and weaknesses of the current methods

Both traditional machine vision and deep learning methods offer unique advantages and challenges in the field. Traditional modes are praised for their speed, though they may struggle in complex scenarios such as changes in brightness or slow-moving vehicles. On the contrary, deep learning methods such as CNNs have remarkable versatility and accuracy but are computationally demanding and sensitive to scale changes in object detection.

9.3 Consider the broader ramifications

Besides their direct applications, these technologies promise to reshape urban planning by improving parking, easing traffic, and reducing fuel consumption and emissions. The broad benefits underscore the urgency of overcoming the current limitations of these technologies.

9.4 Identify areas for further research

Potential areas of focus for future research and development may include improving the detection accuracy of small objects and addressing sensitivity to size changes. As technology advances, it is necessary to investigate and integrate new algorithms to increase the efficiency and effectiveness of smart parking systems.

9.5: Explore potential solutions

One potential solution could be the use of image pyramids or multiscale input images. Although these methods can solve some of the existing problems, they will also increase the computational requirements. Hence, balance and optimization will be key factors.

In conclusion, the future of intelligent parking management depends on the continued exploration and integration of emerging vision-based vehicle detection techniques. As the literature suggests, an innovative blend of traditional machine vision methods and advanced deep learning methodologies could provide the optimal path forward, propelling smart parking systems to new heights of effectiveness and reliability. This continued research is essential to developing increasingly intelligent, efficient, and sustainable urban environments.

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