Automated Parking AI System Using Computer Vision

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I pledge to adhere to the Stevens Graduate Student Code of Academic Integrity, and I have discussed the proposal with my Project Advisor.

***Abstract*—As cities grow, there is a need for innovative parking systems to help drivers identify nearby parking spots. Developed countries have conducted extensive studies on such systems. Car parking management systems fall into four categories: counter-based, wired sensor-based, wireless sensor-based, and image-based. This work describes developing, implementing, and testing an image-based system for detecting vacant parking spaces. After detecting edges, we use edge density and foreground/background pixel ratio to determine if a car is present in each parking spot.**

***Index Terms*—Image Processing, Computer Vision, OpenCV, Parking Spots, Edge Detection, Video Processing**

I. Introduction

A. Challenges of Parking Detection in Urban Environments

The rapid urbanization of our world has led to an explosion in the number of vehicles on the road, making the search for vacant parking spaces a significant urban challenge. This issue is particularly pronounced in high-traffic areas such as airports, train stations, and shopping centers. Studies have shown that 30-50% of traffic in city centers is caused by drivers searching for parking. This underlines the urgent need for effective parking management systems to reduce traffic congestion and minimize the time wasted searching for parking spaces.[1]

1) The Role of Image Processing in Parking Detection: Image-based parking detection systems, utilizing advanced computer vision and image processing techniques, play a crucial role in modern urban parking management. By analyzing video feeds to identify vacant spaces, these systems provide real-time parking information to drivers, helping to alleviate traffic congestion and reduce driver frustration.

2) Integration of Advanced Detection Algorithms: Combining sophisticated image processing algorithms with robust system designs is essential for the effective detection of available parking spaces. These technologies work together to analyze complex visual data and provide accurate information on parking availability, thereby enhancing the functionality and reliability of parking management systems.[5]

B. Optimizing Parking Detection for Enhanced Urban Mobility

The advancement of parking management technology focuses on harnessing the capabilities of image processing enhanced by innovations in machine learning and artificial intelligence.

1) Adoption of Machine Learning and Artificial Intelligence: Machine learning and artificial intelligence are employed to refine the accuracy and efficiency of parking detection systems. These technologies learn from vast amounts of data to improve the detection and prediction of parking space availability, leading to more efficient urban traffic management.[10]

2) Objectives of Optimization: The primary goal is to enhance the operational efficiency and accuracy of parking detection systems. By optimizing these systems, the project aims to support quicker and more effective parking management, facilitating smoother traffic flow and reducing urban congestion.[6]

C. Addressing Urban Mobility and Parking Management Challenges

This research not only pushes technological boundaries but also addresses critical urban mobility challenges, enhancing both safety and efficiency in parking management.

1) Balancing Technological Advancements and Urban Impact: The research balances the advancement of detection technology with the practical challenges of urban parking management. Enhancing system capabilities directly contributes to reducing urban traffic congestion and improving the overall efficiency of urban transportation networks.

2) Detailing the Optimization Process: The integration of machine learning and artificial intelligence with state-of-the-art image processing techniques is detailed, highlighting the methodologies used and the significant improvements in system performance. This discussion underscores the potential of these advanced technologies in transforming urban parking management.

D. Transforming Urban Mobility and Parking Experience

The project aims to revolutionize urban parking management through technological innovation, significantly improving the efficiency and user experience of urban transportation systems.

1) Potential for Revolutionizing Urban Parking: By enhancing parking detection systems with advanced algorithms, this research has the potential to profoundly change how parking is managed in urban environments. Improved detection systems can lead to decreased traffic congestion and a better overall quality of urban life.

2) Vision for Future Urban Living: The successful implementation of these technologies could lead to a future where parking search times are significantly reduced, contributing to the vision of smart, efficient cities. This section discusses the transformative impact of such technologies, emphasizing their role in shaping future urban environments.[3]

Enhancing Parking Management in Complex Urban Environments

The deployment of advanced parking detection systems marks a significant technological advancement, particularly within the complex and dynamic landscapes of urban centers. These systems address critical challenges in parking management by combining high-precision image processing with sophisticated machine learning algorithms. By doing so, they enable real-time, accurate assessments of parking availability, which is crucial for managing urban traffic and improving the overall parking experience.

These urban settings, characterized by their high density and constant flux, demand parking management systems that are not only accurate but also quick and efficient. The integration of cutting-edge technologies is crucial for developing solutions that can effectively navigate these challenges, ensuring that parking management systems contribute positively to the broader goals of urban mobility and sustainability.

Optimizing Parking Detection for Sustainable Urban Mobility

This research is dedicated to enhancing the capabilities of parking management systems through the integration of machine learning and artificial intelligence. These technologies offer new ways to approach the optimization of parking detection, making systems more adaptive and efficient.[12]

The ongoing refinement of these technologies promises to enhance the reliability and operational speed of parking management, bringing the vision of seamless urban mobility closer to reality. As these systems become more integrated into everyday urban infrastructure, they will play a pivotal role in transforming urban transportation landscapes, making them more navigable and less congested.

Addressing the Challenges of Urban Parking Management

The broader implications of this research extend beyond technological enhancements, tackling key issues such as operational efficiency and the feasibility of implementing sophisticated parking management systems in densely populated urban areas. By pushing the boundaries of what is possible in parking detection, this research aims to contribute significantly to the development of smarter, more sustainable urban environments.

This report details the integration of advanced computational techniques with contemporary parking management systems, exploring the optimization process and showcasing preliminary results that highlight the effectiveness of these innovative approaches. The ultimate goal is to present a solution that not only advances parking detection technology but also facilitates the seamless integration of these systems into the fabric of urban life, supporting the development of smarter, more efficient cities.[9]

Transforming Urban Parking and Mobility Experience

This project is about more than just technological advancement; it is about reshaping the urban landscape. By addressing critical challenges related to parking detection and sophisticated algorithmic integration, this research seeks to foster a more efficient and sustainable urban transportation ecosystem. The potential of optimized parking detection systems to revolutionize urban parking management is immense, offering a future where finding a parking spot is no longer a frustration but a seamless part of urban life.

This effort is poised to redefine the potential of parking management technology and its transformative impact on urban mobility and quality of life, paving the way for a future where urban environments are more livable and transportation is more efficient.[1]

II. Problem Statement

Addressing Urban Parking Inefficiencies through Image-Based Parking Management Systems

Urban centers are increasingly grappling with a parking crisis, particularly in densely populated commercial areas. The core issue revolves around the excessive time and fuel that drivers expend in searching for parking spaces, especially during peak hours. This not only causes frustration among drivers but also leads to significant economic losses for local businesses and substantial environmental damage.

1) Economic and Environmental Implications: The inefficiency of current parking solutions directly impacts local commerce by decreasing consumer spending and deterring future visits due to the associated stress of finding parking. Additionally, the environmental cost is non-trivial; excessive driving in search of parking contributes to urban pollution and is a growing public health concern.

2) Urban Traffic Congestion: The quest for parking significantly exacerbates urban traffic congestion. The continual circling of vehicles searching for parking spaces not only increases traffic volume but also impairs overall traffic flow, leading to longer commutes and reduced urban mobility.

3) Data Deficiency in Urban Parking Management: A pivotal challenge in addressing parking inefficiencies is the scarcity of real-time, actionable data. Urban planners and parking facility managers often lack the necessary information to make informed decisions, which perpetuates the inefficient allocation and use of parking resources.[8]

4) Technological Innovation as a Solution: To address these multifaceted challenges, there is a critical need for a transformative approach in parking management. Advancements in technology—particularly in real-time data collection and analysis—offer promising solutions that could evolve parking systems from being reactive to proactive.

5) Proposal for an Image-Based Parking Management System: This research proposes the development of an image-based parking management system that utilizes state-of-the-art image processing and computer vision technologies. This system aims to provide accurate, real-time information about parking availability, thereby alleviating the primary inefficiencies currently plaguing urban parking.

6) System Model and Anticipated Impact: The proposed system model involves the deployment of strategically placed cameras that continuously monitor parking spaces. Advanced algorithms will analyze the visual data to detect vehicle presence, instantly updating the availability of spaces. This approach is expected not only to expedite the parking process but also to facilitate strategic management of parking resources. By improving parking efficiency, the system will significantly enhance urban livability by reducing congestion, supporting local businesses, minimizing environmental impacts, and overall enhancing the quality of urban life. The introduction of this image-based parking management system targets the very heart of the urban parking inefficiency problem. By implementing this system, we expect to transform parking from a tedious chore into an integral, hassle-free component of the urban experience, thereby supporting economic vitality, environmental sustainability, and enhanced urban living. This project represents a pivotal step in urban infrastructure management, aiming to deliver substantial benefits to all city stakeholders. [11]

III. Methodology

In this method, the initial calibration is required using image data of the parking region. In this case, the image has 69 parking slots available in a specific parking region with fixed boundaries. Also, the camera position is stable with no fluctuations. The parking spaces have been defined by using rectangular boundaries. The number of such individual rectangular shapes gives the maximum parking slots available in the targeted parking region. Once this calibration is done, the model is actively ready for usage. Here is the block diagram for the workflow of the whole system.

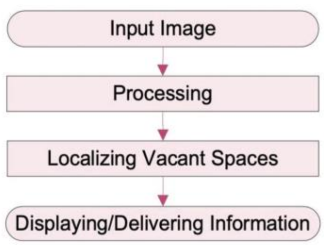

Fig. 1. Initial calibration

In this paper, I have proposed two methods for identifying vacant spaces. The first method is based on the edge detection technique. The second method is based on the foreground and background detection. Both these techniques decide independently, and then we integrate the results from these two approaches into a final decision. The flow chart of this system is provided below.

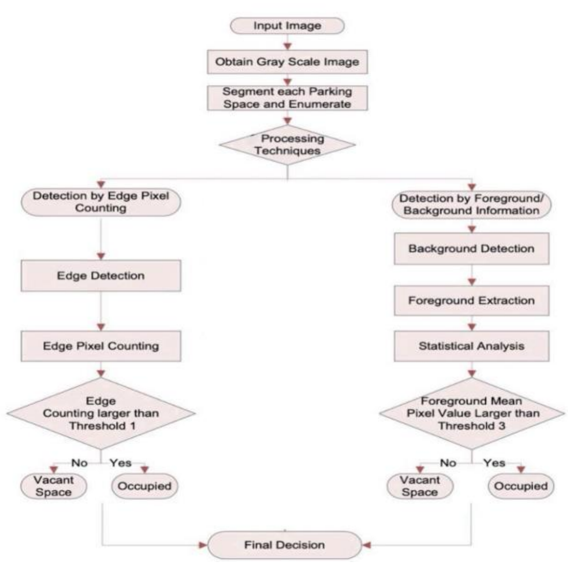

Fig. 2. Flow chart of the Automated AI system

A. Detection by Edge Pixel Counting

The first method implemented in our image-based parking management system is the ”Detection by Edge Pixel Counting.” This technique involves the following steps:

1) Obtain a Grayscale Image : Convert the input image from the parking lot into grayscale. This simplifies the image data, reducing the computational complexity required for edge detection.

2) Segment Each Parking Space and Enumerate : Divide the grayscale image into distinct segments, each representing a parking space. This step is crucial for individually analyzing each space.

3) Edge Detection : Apply an edge detection algorithm, such as the Canny edge detector, to highlight the boundaries of objects within each parking space.

4) Edge Pixel Counting : Count the number of edge pixels in each segmented parking space. Edge pixels indicate the presence of distinct shapes or objects, like vehicles.

5) Edge Pixel Counting : Count the number of edge pixels in each segmented parking space. Edge pixels indicate the presence of distinct shapes or objects, like vehicles.

6) Decision Making : Decision Making: Compare the count of edge pixels against a predefined threshold. If the count exceeds the threshold, the space is classified as occupied; otherwise, it is considered vacant.

The rationale behind using edge pixel counting is its effectiveness in distinguishing occupied spaces from vacant ones based on the clear visual differences between an empty space and one containing a vehicle. Vehicles typically have defined edges and shapes that significantly alter the edge pixel count in an image. This method is advantageous because it is less susceptible to variations in color or brightness, making it reliable under different lighting conditions.[14]

B. Detection by Foreground/Background Information

The second method, ”Detection by Foreground/Background Information,” involves a more complex analysis that includes:

1) Background Detection: Identify and model the background of the parking lot image, which includes areas consistently devoid of vehicles over time.

2) Foreground Extraction: Subtract the background model from the current image to isolate new elements in the scene, primarily focusing on vehicles.

3) Statistical Analysis: Conduct a statistical analysis of the foreground elements, focusing on metrics like the mean pixel value.

4) Decision Making: Compare the statistical data against another set of thresholds to determine whether a space is occupied. A significant deviation from the background statistics, such as a higher mean pixel value, suggests occupancy.

This method leverages the dynamic differences between the static background and the variable foreground, where vehicles present as new elements in the scene. The use of background subtraction is particularly effective in environments where the background remains relatively unchanged, allowing the system to detect new objects with high precision. This method is superior in scenarios where edge detection alone might fail, such as in highly textured parking surfaces or in varying weather conditions that might obscure clear edge definitions.

C. Comparative Performance Analysis

The parking management system utilizes two primary image processing algorithms to determine the occupancy of parking spaces from video feeds. These methods, Detection by Edge Pixel Counting and Detection by Foreground/Background Information, leverage distinct image processing techniques to enhance the accuracy and reliability of detecting parking space occupancy.[5]

1) Detection by Edge Pixel Counting: This method employs edge detection algorithms to analyze the edges within each designated parking space. The process begins by converting the input image to grayscale, simplifying the detection of edges by reducing the data's dimensionality. Common edge detection algorithms such as the Sobel or Canny detectors are then applied to delineate the boundaries of objects within the image. The system counts the pixels forming these edges and compares the count to a predefined threshold to determine the occupancy status of the parking space. A high number of edge pixels generally signifies the presence of a vehicle, marked by its pronounced edges contrasted against the background of the parking lot.

2) Detection by Foreground/Background Information: In contrast, the Foreground/Background Information method uses a more sophisticated technique involving background subtraction and statistical analysis. Initially, this method develops a background model of the parking lot by analyzing video frames when the parking spaces are known to be vacant. Subsequent frames are compared to this background model to isolate the foreground, which represents new elements in the scene, including parked vehicles. This method is particularly effective in dynamic environments where lighting conditions and vehicle movements frequently change.[7]

Fig. 3. Grayscaled image for foreground/Background Information

IV. Experimental Setup and Execution

A. Introduction to the Experimental Framework

To assess the efficacy of the proposed image-based parking management system, a controlled experimental framework was utilized within the PyCharm Integrated Development Environment (IDE). This subsection elaborates on the software and hardware configurations, methodologies employed, and the steps taken to guarantee reliable and reproducible outcomes.

B. Development Environment Configuration

Experiments were conducted using a standard computer suitable for image processing tasks. PyCharm was selected for its comprehensive support of Python development. A virtual environment was established within PyCharm to manage dependencies, ensuring that the project's environment is isolated from the global Python environment to enhance reproducibility.

C. Virtual Environment and Dependency Management

The virtual environment was created using Python's built-in `venv` module. This setup encapsulates all necessary executable files and libraries in a directory specific to the project, simplifying dependency management and avoiding potential conflicts with globally installed Python packages.

D. Installation of Required Libraries

Critical Python libraries for image processing and data handling were installed within the virtual environment, including:

- `numpy` - for numerical computations and array handling.
- `opencv-python` (OpenCV) - for real-time computer vision operations.
- `cvzone` - to facilitate the use of OpenCV functions, enhancing video feed overlays.
- `sklearn` - for advanced statistical models and performance metrics.

These libraries were installed using `pip`, ensuring that only compatible versions were used.[3]

E. Preliminary Code Setup

The initial phase of the experiment involved executing a Python script that configured the parking management system. This script allowed for manual segmentation and annotation of parking spaces using OpenCV's mouse click events to delineate parking spaces and store their coordinates in the `posList`, while occupancy status was recorded in `groundTruth`. These data were serialized using Python's `pickle` module for subsequent real-time analysis.

F. Data Serialization and Transfer

After configuring the parking spaces, the `posList` and `groundTruth` data were serialized into binary format using the `pickle` module and saved to disk. This ensured that the configuration data could be reliably transferred and reloaded into the subsequent experimental phase without loss of data integrity.

G. Real-Time Video Analysis

In the second phase, the serialized data were loaded into a new Python script responsible for real-time video analysis. This script processed continuous video feeds of the parking lot, applying designated image processing algorithms to assess each parking space's occupancy. Real-time video capture was managed using OpenCV's `VideoCapture` function.[10]

H. Image Processing and Decision Making

During video processing, each frame was converted to grayscale and processed using either edge detection or background subtraction, depending on the algorithm selected. The processed data were then compared against predefined threshold values to determine the occupancy status of parking spaces, with the results visually displayed on the video feed—occupied spaces were marked in red and unoccupied in green. [13]

I. Performance Evaluation and Metrics Calculation

Throughout the experimentation, critical performance metrics such as accuracy, precision, and F1 score were computed using the `sklearn.metrics` module. These metrics provided quantitative insights into the performance of the parking management system, guiding further refinements and optimizations.

V. Numerical Results and Analysis

A. Results of Calibration

Initial tests were conducted using several images taken from outdoor parking areas, covering a total of 69 parking spaces. The images were captured using an off-the-shelf camera. An example of an image with a vacant parking space is illustrated below to showcase the initial calibration using the OpenCV library.

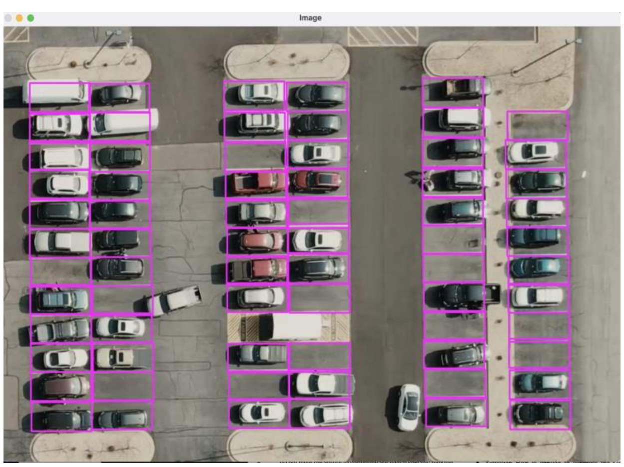

Fig. 4. Initial calibration using OpenCV

B. Results of Converting Color Image to Binary Image

After converting the image to grayscale, the OpenCV library employs an adaptive threshold binary inverse method to enhance image processing. This method adapts to varying illumination levels in the image, providing an accurate binary representation where the foreground is represented by white pixels, and the background is black. This is crucial for isolating and extracting features for further analysis.[6]

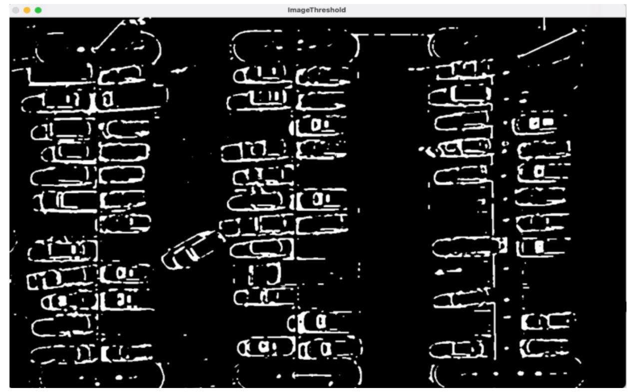

Fig. 5. Binary Image after adaptive thresholding

C. Prediction of Vacant Spaces in the Parking Region

Each parking slot is analyzed for its pixel count to determine occupancy. Slots with less than 900 pixels are categorized as vacant. This method allows for a clear distinction between occupied and unoccupied spaces, as depicted in the figures below.

Fig. 6. Vacant parking slot

Fig. 7. Filled parking slot

D. Detection of Parking Slots at First Frame of Video

The initial frame of the video analysis shows the parking slot occupancy, providing a real-time snapshot of available spaces.

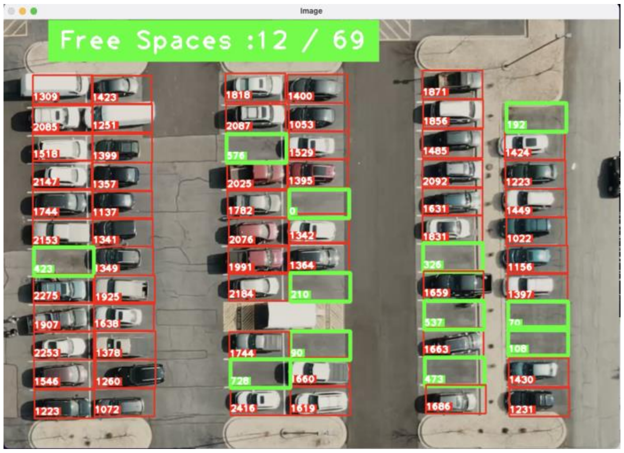

Fig. 8. Detection of Parking slots at First Frame of Video

E. Detection of Parking Slots at Last Frame of Video

The final frame of the video clip demonstrates changes in the parking lot's occupancy, updating the number of free spaces as vehicles depart.

Fig. 9. Detection of Parking slots at Last Frame of Video

This section presents a comprehensive analysis of the effectiveness of the image-based parking management system. Through detailed experimentation and image processing, the system's ability to accurately detect and report parking availability in real-time is affirmed, enhancing urban parking management and offering significant improvements in traffic flow and environmental impact.

F. Metric Evaluation and Frame Analysis

1) Overview of Metric Evaluation: The parking management system employs image processing techniques to determine parking space availability, using key performance metrics like accuracy, precision, and F1 score for evaluation. These metrics assess the system's reliability and effectiveness in real-world scenarios.

2) Initial Frame Analysis: The first frame analysis demonstrates the system's robustness in identifying occupied and free parking spots with high accuracy and precision.

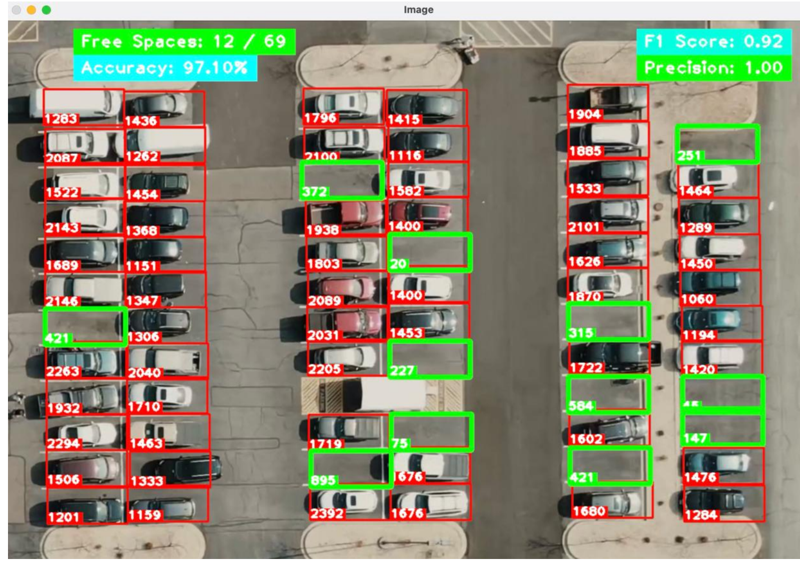

Fig. 10. Initial frame showing parking occupancy

3) Accuracy and Precision:

- **Free Spaces:** Initially, the system identified 12 out of 69 spaces as free, indicating most spots were occupied.
- **Accuracy:** The accuracy achieved was 97.10%, highlighting the system's reliability.
- **Precision and F1 Score:** A precision of 1.00 and an F1 score of 0.92 confirm the system's efficacy in classifying spaces correctly.

4) Last Frame Analysis: The analysis of the final frame shows an increase in free parking spaces, reflecting the dynamic nature of the parking lot environment.

Fig. 11. Final frame with updated parking occupancy

5) Changes and Stability of Metrics:

- **Free Spaces:** Increased to 15, suggesting vehicles had left the parking lot.
- **Accuracy:** Improved to 98.55%, further affirming the system's effectiveness.

- **F1 Score and Precision:** The F1 score increased to 0.97, while precision slightly decreased to 0.93, likely due to new vehicles entering or adjusting within the lot.

G. Comprehensive System Evaluation

This detailed evaluation over multiple frames provides insights into the system's performance, illustrating its high reliability and adaptability in monitoring parking status.

1) Video Stability and Environmental Factors: Despite slight shakiness and variable lighting conditions, the system maintained high performance metrics, showcasing the robustness of its image processing algorithms.

2) Implications for Real-World Applications: The consistent high performance across various conditions demonstrates the system's potential for real-world applications, where such precision and adaptability are crucial for efficient parking management. The continuous performance analysis across different frames confirms the system's capability to handle real-world complexities effectively. The detailed metric evaluation emphasizes the system's potential to enhance urban parking management, improving both driver experience and operational efficiency.[8]

VI. Conclusion

This project has successfully demonstrated the viability and effectiveness of an image-based parking management system, aimed at resolving the persistent challenge of parking space availability in crowded urban environments. By employing advanced image processing techniques and utilizing the OpenCV library, the system has shown exceptional capability in identifying vacant and occupied parking spots, providing real-time data essential for efficient parking management.

A. Project Methodology and Results

A robust methodology was implemented, comprising development, testing, and refinement of algorithms that enhance the detection of parking spaces. The system's performance, indicated by consistently high metrics such as accuracy, precision, and F1 score, confirms its reliability across various environmental conditions and parking scenarios. This not only reduces the time drivers spend searching for parking but also contributes to decreased traffic congestion, reduced emissions, and overall improved urban mobility.[13]

B. System Flexibility and Scalability

The system's flexibility was evidenced through its successful application in a simulated environment, showcasing its adaptability to various parking facility scales, from small retail lots to large airport parking areas. Continuous monitoring and analysis of parking dynamics enable facility managers to make well-informed decisions, optimizing resource allocation and operational efficiency.

C. Implications for Urban Infrastructure

The project highlights the critical role of integrating advanced technology with traditional urban infrastructure to tackle contemporary challenges. It illustrates how intelligent systems can transform urban environments into more sustainable and user-friendly spaces.

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