

Vision-Based Smart Parking System for Campus Vehicles

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Abstract

The parking slots in the campus or the city area provide visual information, which is an important aspect in the efficient utilization of the parking slots. The traditional approach in monitoring the parking slots is not efficient, and many inaccuracies are present in the traditional approach, which may cause congestion and inefficient utilization of the parking slots. The proposed research is focused on developing a production-ready smart parking system that accurately detects the parking slot using computer vision. The proposed smart parking system accurately detects the parking slot using computer vision by employing image processing techniques for the accurate detection of the improperly parked vehicles. The proposed smart parking system may be developed by employing image processing techniques for the accurate detection of the parking slot.

Keywords: Smart Parking System, Computer Vision, OpenCV, Real-Time Monitoring, Parking Slot Detection, Improper Parking Detection, Image Processing.

1. Introduction

Smart parking systems can thus be described as a new approach to parking management, which involves the use of computer vision and image processing in parking space monitoring and analysis. The expansion of learning institutions and urban centers has made smart parking management a necessity in order to manage the increasing number of vehicles. One of the major problems associated with traditional parking management systems is the presence of inefficiencies and irregularities in parking, which always have a negative impact on parking space management. The inefficiencies and irregularities in parking management can be attributed to various factors. The impact of such traditional gaps in the management process is seen in various repercussions like the occurrence of traffic congestion, wastage of fuel, time, and parking efficiency. Monitoring techniques like sensor-based monitoring and manual monitoring are available; however, they are costly and difficult to implement at larger scales and cannot cope with the dynamic environment. Research is showing signs of the automation process, and surveys conducted recently show the development of smart city technology with vision-based parking monitoring being more flexible and cost-effective

compared to sensor-based parking monitoring systems [1]. With regard to these problems of failure of the system, a number of automatic architectures have been proposed. Most of the sensor-based systems and human supervision methods are easily Moreover, the development and implementation of such systems are also essential for the achievement and realization of the objectives for urban sustainability. Research indicates the need for the development and implementation of effective smart parking systems, which are not only limited to parking detection but are also essential for the optimization of resource allocation and reservation systems for the effective management and control of traffic flows [2].

2. Literature Review

The development of parking monitoring systems has moved from physical inspections to highly advanced computer vision-based systems. Surveys that were conducted recently indicated that smart city technologies are being improved, and vision-based parking monitoring is more flexible and cost-effective than sensor-based parking monitoring systems [3]. Smart parking is not only limited to object detection; it is also limited to optimal resource

allocation and reservation for improved traffic flow. Recent developments in object detection in complex environments are highly advanced using models such as YOLO and Faster R-CNN [11, 12]. Although object detection is possible using single-frame analysis in complex environments, it is highly difficult to implement it in real-time environments because of various complexities. In order to avoid false object detection because of temporary environmental changes because of moving vehicles and reflections of lights, it is highly necessary to use temporal validation of frames. In recent developments of real-time object detection, pixel intensity evaluation is highly efficient for slot-wise classification of objects as occupied or unoccupied spaces [5]. Although recent developments of ultrasonic-based detectors indicated that it is possible to use them for providing occupancy information, it is highly insufficient for improper parking and vehicles in multiple slots. In addition, complex feature extraction methods, such as Speeded-Up Robust Features (SURF), may be employed to identify particular features of the vehicle in the image [8]. Fundamentals of Image Processing - Even though this method may not be considered an advanced method, the basic concepts of image processing lay the foundation for the processing of images for detailed analysis [9].

3. Methodology

The proposed smart parking system is based on a modular processing pipeline that enables the efficient management and processing of various components of the smart parking system. With the help of the proposed smart parking system architecture, it is possible to enable a parking slot detection mechanism in real-time. Along with the parking slot detection mechanism, it is also possible to offer a web-based monitoring interface with the help of the proposed smart parking system.

- **Data Ingestion and Preprocessing**

Essentially, it can be stated that the operational efficiency of a vision-based smart parking system is significantly dependent on the quality of the initial data flow and the accuracy of data refinement. The data refinement process begins with the Data Ingestion phase, in which a direct communication

link is established with high definition cameras that are strategically placed to oversee the parking facility. The input data is represented as a high-bandwidth flow of raw video frames that capture multiple parking slots simultaneously and act as input data throughout the data refinement process. In order to effectively process such a large amount of data without any form of latency, it is able to leverage the OpenCV library in order to effectively ingest that data and process it on a very stringent frame-by-frame basis. At this point in the system, regions of interest (ROI), which is based on the physical location of each of the parking slots, is effectively extracted from the frame based on a set of very carefully defined coordinates. At this point in the system, there is no wastage of resources on any form of background information such as walkways or any other views of the parking area, but rather a very focused view of the parking slots themselves. Once it is ingested into this system, it is then processed and passed into the Data Preprocessing module, which has the responsibility of ensuring the absolute integrity and clarity of the data before it is subjected to classification. However, it is to be noted that in real time scenarios, raw video frames are never in perfect condition and are always plagued with a number of issues and challenges, which can be categorized into electronic interference, unpredictable changes in lighting, and complex patterns of shadows resulting from clouds or man-made lamps suspended over the area of interest. To ensure that this data is not unduly influenced by these factors, a number of complex processes are undertaken within this module to enhance the quality of the data. First and foremost, grayscale conversion of the data is undertaken, which is basically a conversion of this three-dimensional color image into a one-dimensional intensity image, thereby mathematically reducing the complexity of the data and hence increasing the rate of processing. This is then followed by a Gaussian blur filter, which helps to remove high frequency noise and minor pixel changes, which could be misinterpreted as features of vehicles. However, in order to segment the vehicle of interest from the asphalt background, primary thresholding is applied to enhance the potential vehicle region of interest. Nevertheless, bearing in

mind that parking lots are usually exposed to extreme levels of brightness, ranging from the glare of the sun in the morning to the dull lighting in the evening, adaptive thresholding is used to determine the thresholds of brightness in the image [4]. This will ensure that despite being placed in deep shades, it will always be detectable by the detection engine. Finally, morphological operations are applied to ensure the reliability of the areas that have already been detected by filling up the gaps in the vehicle's shape and ensuring that the pixel areas are made equal to the actual size of the vehicle. By this comprehensive approach of robust ingestion and multi-layered preprocessing, it is ensured that the final data set is refined, high contrast, and free of noise, which is essential to provide a solid ground for classification of parking slots.

3.1. System Setup and Configuration

In order to utilize the proposed smart parking system, it is essential that the required software is properly configured in the system. The proposed parking system has been developed by utilizing the python programming language and the required library tools such as OpenCV, NumPy, and Stream lit. The user must ensure that the required library tools are properly configured in the system, along with the video source that has been properly connected to the parking slot by utilizing the parking surveillance camera or parking video source. The predefined parking slot coordinates must be properly loaded into the system so that the parking slot can be analyzed individually. Once the required configurations have been properly completed, it is possible to process the parking slot properly shown in Figure 1.

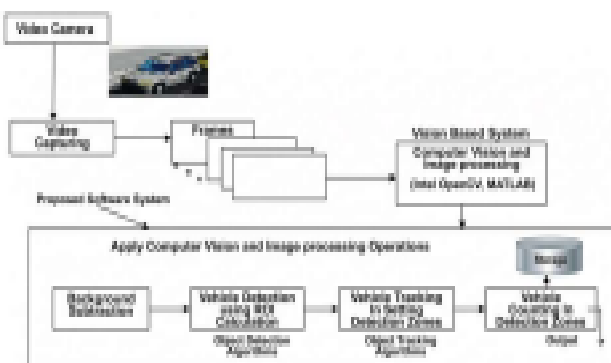


Figure 1 System set up

3.2. Maintaining System Performance and Accuracy

In order for the smart parking system to be efficient, it is imperative that the slot configuration that has been previously defined is maintained. The boundary of the parking slot in terms of pixels and preprocessing value have all been previously defined in order for the accuracy of the vehicle's detection to be ensured [7][8]. Therefore, any changes in the value may affect the efficiency of the smart parking system. The smart parking system can be considered efficient despite the changes that may occur in the lighting conditions or the environmental changes. It is recommended camera be fixed in order for the smart parking system to be effectively utilized.

3.3. Slot Classifications and Validation

The final decision regarding the status of a parking spot is conducted in the Slot Classification and Validation module, wherein visual data is converted into useful information regarding slot occupancy status [6]. A rule-based decision mechanism is utilized in classifying the status of a parking slot based on structured data learned in previous stages of processing. The main classification is based on a threshold value of pixel intensity. Based on the number of non-zero pixels present in a fixed boundary of a slot after adaptive thresholding is applied, it is possible to differentiate asphalt from a vehicle. The basic idea is based on a binary classification model. If the total count of activated pixels at a particular set of coordinates for a slot is greater than a specific threshold value determined by using mathematical calculations, then it is marked as occupied; otherwise, it is marked as empty. This threshold-based idea can be determined by using the following decision function:

$$f(S) = \{1(Occupied), 0(Empty)\} \text{ if } \sum_{i=1}^n n P_i > \tau$$

Where P_i is the intensity value of an individual pixel of the slot (S), and n is the number of pixels of the slot region, and τ is defined as the pixel intensity threshold. It is noticeable that the sensitivity value τ is changeable, and it is set according to the environment or the resolution of cameras.

In order to attain high reliability and prevent false positives, this system also employs Spatial and

Temporal Validation. In Spatial Validation, there is a thorough verification of the object's position in relation to the boundary conditions that are established in the slot. This is to ensure that the system does not incorrectly identify a vehicle as being parked when it is actually passing through or when it is parked in a position that spans multiple boundaries. To complement this, Temporal Validation is used as a consistency checker for a sequence of consecutive video frames. This is different from the snapshot, which may be deceptive because of the presence of a sudden glare, flying of a bird, or cast of a shadow. The temporal module will check and verify the status only if the status is maintained for a certain period of time. This is a multi-level validation process that ensures that there is no false reporting because of environmental changes over short periods of time, thereby providing a reliable solution for the campus environment.

3.4. System Architecture

The basic architecture of the proposed smart parking system is based on the incorporation of a state-of-the-art computer vision module that is specially designed and engineered to deliver accurate parking slot detection. Unlike other sensor-based parking systems that need special hardware to be installed in each parking slot, the proposed parking system is based on the incorporation of a state-of-the-art image preprocessing and pixel analysis technology to convert visual images into intelligent parking slot detection. The proposed parking system is based on the incorporation of a two-level analytical framework that delivers efficient and accurate observation accuracy in a short time, with special emphasis on the incorporation of image processing technology for slot detection. The first level of this framework is the spatial slot detection level, which depends on the geometric and intensity-based attributes of each parking region. Once the video frame is introduced into this framework, it is able to detect the parking slot region based on predefined coordinates and perform threshold-based pixel intensity evaluation. The idea behind this level is based on the fact that any physical object will surely impact the pixel density and intensity relative to an empty asphalt surface. By looking into the internal pixel environment of this

region, it is able to quickly and accurately determine whether it is occupied or not based on the input video frame. In order to further enhance the level of confidence in the results obtained from the initial classification process, it is proposed that the system would incorporate a temporal validation module. It has been observed that the spatial analysis process is highly efficient for the detection of objects in a single frame. However, in the real world, there are certain environmental issues that would affect the scene. For instance, there would be a sudden glare in the scene, or there would be people walking in front of the parking slots shown in Figure 2.

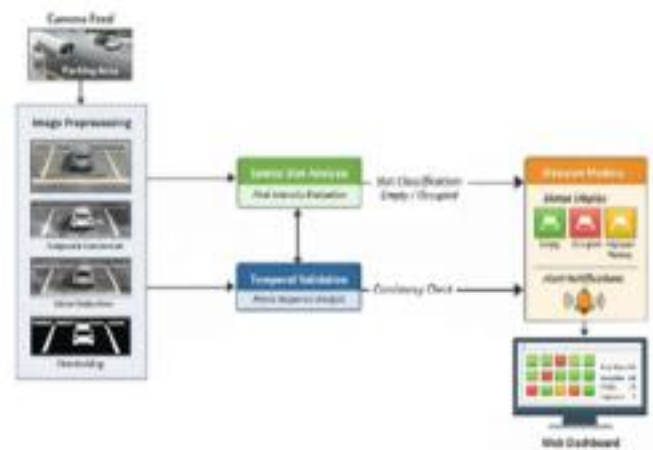


Figure 2 System Architecture

4. Results and Analysis



Figure 3 Performance of System

From the above figure, it can be clearly understood that the performance of the system is validated with

the usage of video data in parking lot scenarios. In the video data, various scenarios are considered, and the scenarios include empty slot, occupied slot, temporary obstruction, and improper parking. Based on the experimental observation of the proposed system, it can be clearly understood that the proposed system is capable of detecting the status of the parking slot with various lighting conditions and vehicle position [10] [13]. It can also be observed that the proposed method of spatial and temporal validation is effective in detecting the rate of false alarm. Temporary shadow and passing of cars are not considered as a car because of the proposed temporal validation module, which checks the consistency of the detected vehicle in subsequent frames. Improperly parked cars are detected in multiple slots by using the proposed boundary validation module. The proposed web dashboard is a clear representation of the parking lot's status. The number of slots, occupied slots (red), empty slots (green), and improper parking (orange), are represented by using the proposed web dashboard. The sensitivity of the proposed module can be changed by varying the pixel value shown in Figure 3.

4.1. Limitations

However, it is hindered in its current state due to the high hardware costs of sensors or human error in supervision. It also does not offer live updates and is not able to identify wrongly parked cars that are occupying multiple parking slots.

4.2. Gap Fulfillment and Future Enhancements

The proposed system has addressed the limitations of the existing system by providing a vision-based system that is cost-effective and real-time without any physical sensor placement. The proposed system is effective for identifying misuse of parking space and presence of occupants by proper elimination of environmental noise such as shadows through spatial pixel analysis and validation. Considering the future direction of the proposed system, there is a possibility of using deep learning-based models such as YOLO to improve accuracy.

5. Conculural Work

The proposed smart parking system requires continuous video input from CCTV or IP cameras; otherwise, its detection performance may degrade.

Proper threshold tuning is necessary during initial deployment to ensure optimal performance of the hybrid detection mechanism. In certain extreme conditions such as heavy shadows or severe occlusion, the system may produce minor false positives or negatives. Future work includes developing adaptive thresholding techniques to automatically adjust to varying lighting conditions, integrating deep learning models for accuracy, and implementing cloud-based or federated systems for scalable and privacy-aware deployment. Enhancing these aspects will improve the robustness and adaptability of the system, making it more efficient for real-time parking management. This system is achieved through the use of pixel-based detection for identifying occupancy and spatial boundary analysis for detecting parking violations. The evaluation of the proposed approach is also carried out using basic threshold-based detection, pixel-only detection, and the hybrid approach. From the results, it is evident that the proposed hybrid method achieves higher accuracy compared to individual techniques.

Conclusion

The idea of "Park Vision" and its development and implementation are a breakthrough in moving from conventional hardware-based parking management to intelligent vision-based parking management. With this research, the issue of inefficiencies and irregularities in conventional parking lots, such as parking lots without supervision and visibility, is successfully resolved. The proposed system successfully bridges the existing gaps in technology with a cost-effective solution for expensive sensor technologies that are not efficient in resolving intricate issues such as improper parking in multiple parking spaces. However, with the help of the two-tiered analysis method, where spatial pixel intensity evaluation and temporal consistency validation are carried out, it would be possible to obtain high-fidelity results regarding the occupancy classification of the parking space, while at the same time ensuring that the system remains immune to environmental noise such as moving shadows, glare, and even pedestrians. This would not only help in classifying the parking space, whether it is occupied or not, in any particular frame of reference, but would also help

in ensuring the consistency of such data over a series of frames, thereby creating a reliable data stream, which could then be made use of by the administrators. Moreover, the visualization of the data, using the Streamlit interface, would help to make this tool even more useful, so that aberrant parking behavior could be prevented.

Essentially, this project is in line with the objectives of various infrastructure and sustainability goals across the globe, such as SDG 9 and SDG 11. With "Park Vision" reducing the time and fuel consumption associated with identifying available parking space, it is part of an initiative to reduce the carbon footprint of urban and campus-based mobility. Further enhancements to this system, such as the utilization of deep learning-based algorithms such as YOLO even in extreme weather conditions or edge computing to reduce latency, only add to the refinement of such systems. Conclusion: With this research providing a production-ready base for intelligent parking management systems that is malleable to the needs of an ever-evolving smart city infrastructure.

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