Parking Lot Vacancy Notification System

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Contents

Abstract

The lack of parking spaces has become a serious issue in many public places, especially in university campuses where the number of vehicles is high and space is limited. This project proposes a parking space management system to address these issues, and the feasibility of solving the problem was verified through the design, implementation, and evaluation of the system. The system aims to improve the efficiency of parking management by detecting the status of parking spaces in real time and providing users with information that takes into account vehicle size and space suitability. As a result of the implementation, the proposed system succeeded in improving both accuracy and convenience compared to the existing methodology, and the evaluation demonstrated the practical effectiveness of the system. On the other hand, limitations such as performance degradation under certain conditions were also identified, and solutions and future

improvement directions were discussed. This project is significant in that it goes beyond the simple implementation of the system and presents new possibilities for smart parking management.

Keywords: parking management system, YOLOv5, real-time object detection, space car detection

1 Introduction

The lack of parking spaces is a real challenge that many people face every day. Especially in the modern world, where the number of vehicles is constantly increasing, the efficient utilization and management of space is becoming increasingly important. Specifically, six out of 10 Korean drivers are stressed by parking problems on a daily basis[2], and nine out of 10 have wasted time even after reaching their destination due to parking problems[1]. This problem stems from the limitations of traditional parking systems that fail to take into account vehicle size and the suitability of the parking space. This is especially true in public spaces such as universities, where it leads to time wastage, traffic congestion, and environmental pollution.

Parking lot expansion essentially solves the problem of parking shortages, but it's a difficult solution to use in schools, where most spaces are already compressed[3]. In response, parking apps that can check parking spaces in real time have emerged as a solution[1], but there is no service targeting Sungkyunkwan University. In addition, the existing parking system mainly detects only the availability of parking spaces and does not consider the size of the vehicle. It can lead to a decrease in user convenience if parking spaces are provided uniformly despite the fact that parking spaces vary depending on the size of the vehicle, and even worse, if there are not enough parking spaces available, large vehicles may try to park in small spaces, causing traffic congestion or increasing the risk of accidents. Therefore, there is a need for a smart parking management system customized for Sungkyunkwan University that considers vehicle size.

This project focuses on enhancing parking space management efficiency and user convenience by introducing a system that evaluates parking space availability with additional considerations for vehicle size categories. Unlike conventional systems that only identify empty spaces, this solution specifically detects large vehicles, such as trucks, and marks nearby parking spaces in yellow to indicate potential limitations. This visual cue enables users to make informed decisions when selecting parking spots, improving the overall parking experience. The system operates using a camera-based approach combined with detection algorithms to monitor parking lots in real time. Strategically positioned cameras capture images, which are then processed through an optimized object detection model. This model identifies available parking spaces and detects the presence of large vehicles, updating the system to reflect changes dynamically. A mobile application displays this information through an intuitive interface, providing users with a clear overview of the parking lot. By incorporating this functionality, the system ensures effective space utilization while addressing the challenges posed by parking near larger vehicles. The approach maintains seamless integration from image capture to user interaction, leveraging a robust database and real-time data flow. This solution simplifies parking decisions for users and improves overall parking lot management efficiency.

The report first details the design and configuration of the proposed system and covers the techniques and approaches used during the implementation. The performance and limitations of the system are then analyzed through evaluation, and the implications of this project are discussed through comparison with related work. Finally, a discussion including limitations and possible improvements suggests directions for future research and concludes with a comprehensive evaluation of the potential for new parking management presented by this project.

2 Design for the Proposed

2.1 Overall Architecture

2.1.1 Real-Time Capture with Cameras

First, to cover all the areas of the SKKU parking lot, we divided the parking lot area into four sectors and used a camera for each sector. The videos of sector A and B are captured on the rooftop of the Engineering 1 building and sector C and D are captured on the rooftop of School of Pharmacy

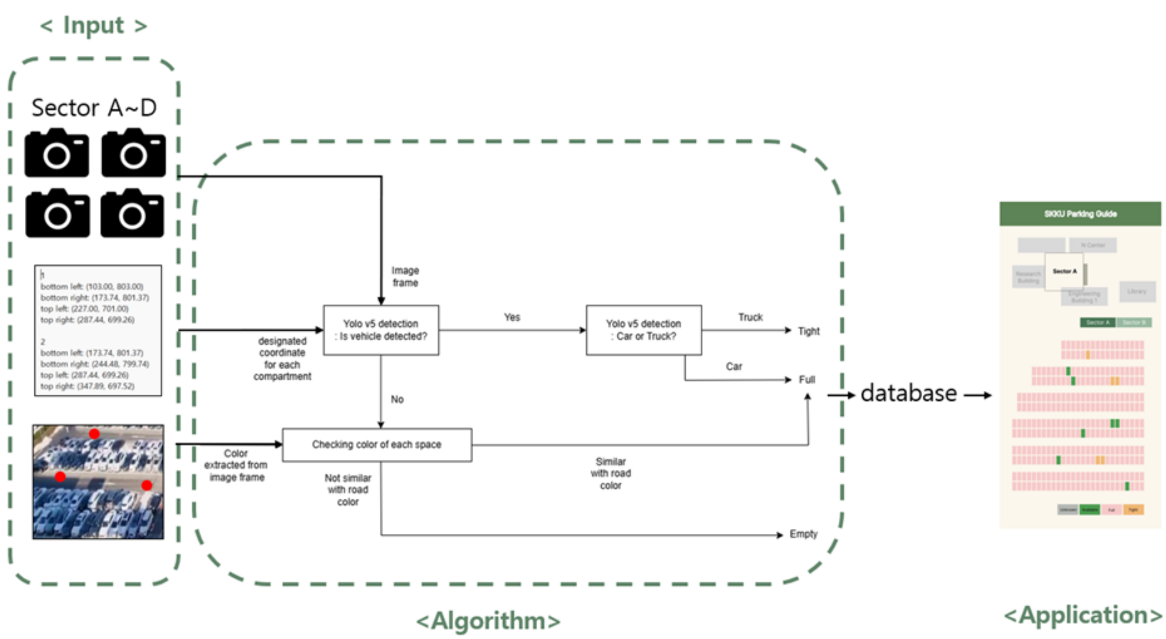

Figure 1: Overall Architecture

building. Each sector A has spot 1 162, sector C has spot 163 294, sector B has spot 295 384, sector D has spot 385 474. And for each sector, we made coordinates text file to match the detected car with the spots. The coordinates include the spot id, bottom left, bottom right, top left, top right coordinates of each space. We use each sectors' video frames and coordinates to make SKKU Parking Guide.

Figure 2: SKKU parking lot captures from the rooftop of the buildings

2.1.2 Algorithm Flow

Each sector's video is cut into frames every 25 seconds, and fine-tuned YOLO model detects cars on that frame and compare with the coordinates of each space. If a car is detected in the space, we put additional truck detection to determine the narrow space of the parking lot. If a car is not detected in the space, we double check with the color of the parking lot space to ensure that there does not exist any car in that space. Then we send the data in form of 0: empty, 1: car, 2: truck to database and application receives that data and shows the users with the color of green for empty, red for occupied and yellow for nearby truck space.

2.2 Model and Algorithms

2.2.1 Detection by YOLOv5s Model and Its Metrics

We used pretrained YOLOv5s model from ultralytics that has been trained on the COCO dataset. YOLOv5s model works well with real-time detection and it is highly efficient on the limited computational resources. The model is fine-tuned with 'CARPK' car dataset and the truck dataset. The car dataset contains 314 images with only class car and the model trained with the car dataset and 10 epochs had result of 0.978 of precision, 0.962 of recall and 0.983 of mAP-50 metrics. The truck dataset contains 4266 images with class bus, car, motorcycle and truck. The model trained with the truck dataset and 10 epochs had 0.854 of precision and 0.829 of recall, 0.881 of mAP-50 metrics.

	CARPK	**Truck dataset**
Precision	0.978	0.854
Recall	0.962	0.829
mAP-50	0.983	0.881

Table 1: Metrics of the model trained with Car Dataset and Truck Dataset

We fine-tuned the YOLOv5s model with each dataset and tried to detect the cars with the model trained with the car dataset first and detect truck with the detected cars.

2.2.2 Matching Object with Parking Lot Space Algorithm

After the detection of the YOLO models, we made an algorithm to match the detected cars with the parking lot spots. The detected cars are saved in the form of (class, center_x, center_y, width, height) in each line. For each parking lot spot area, if any center point of detected car exits in that area, we labeled the area as occupied. After checking all the area with all detected cars, if none of the car center points were matched with the area, we labeled the area as empty.

2.2.3 Color Detection Algorithm with HSV

After matching the detected car with parking lot spots, we added another color detection algorithm for the empty spaces. If the model fails to detect a car, it would result in an occupied spot being displayed as empty to the user and it is a huge problem of the project. To prevent this, we set the parking lot asphalt color in HSV form. HSV displays the color with Hue, Saturation and Value (Brightness). So, we made a range of asphalt colors with Hue in 0 179, Saturation in 0 50 and Value in 80 160. For every empty space, if more than 15 percent of the area color is in that HSV range, it is still labeled as empty but if it is less than 15 percent than it is labeled as occupied.

2.3 Challenges and Solutions

2.3.1 Color Detection by Extracting Colors from Frames

As explained above, we used the parking lot's average asphalt's color to use the color detection algorithm. However, there was a problem that asphalt color shown on the image depends on the time, light, and shades. So, we decided to extract color from the frame image to reflect the variation of the color range of the parking lot.

Figure 3: Parking Lot “Empty” spot colored with green and “Occupied” spot colored with red

2.3.2 Fixing the Camera Angle

To make the system work in real-time, it was important to make the camera angle fixed to maintain the frame same. Because we used the saved coordinates of the parking lot spots to match the spots with the detected cars, even a brief shake in the camera angle can significantly impact the accuracy. Therefore, the camera mounts were created by using a 3D printer and were fixed on the rooftop to make the camera angle same.

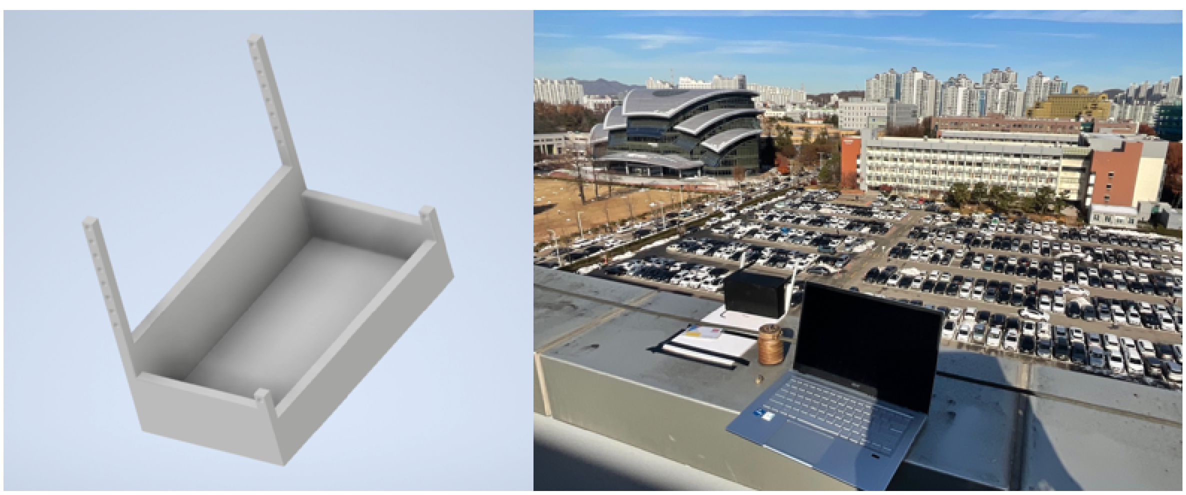

Figure 4: Hardware design to fix the camera angle

2.3.3 Adjusting Center Points of the Cars Algorithm

While matching the detected cars with the parking lot spots, we found out that some detected cars do not match the its spot's coordinates exactly. The left picture in Figure 5 shows that the white car is on the second bottom-left spot but because of the perspective of the camera the car's center point is not included in the second spot area so it displays that there is no car existing in that area. So, we decided to adjust the center points of the detected cars. Because we put the camera at the center of the parking lot sector, the cars on the side of the parking lot do not match well with the parking lot spots. So, we made the center points of the cars on the side to move more to the center, and cars on the center hardly change. Also, the center points of cars in front of the camera moves more to the center than the cars at back of the camera because the front row looks longer than the back row.

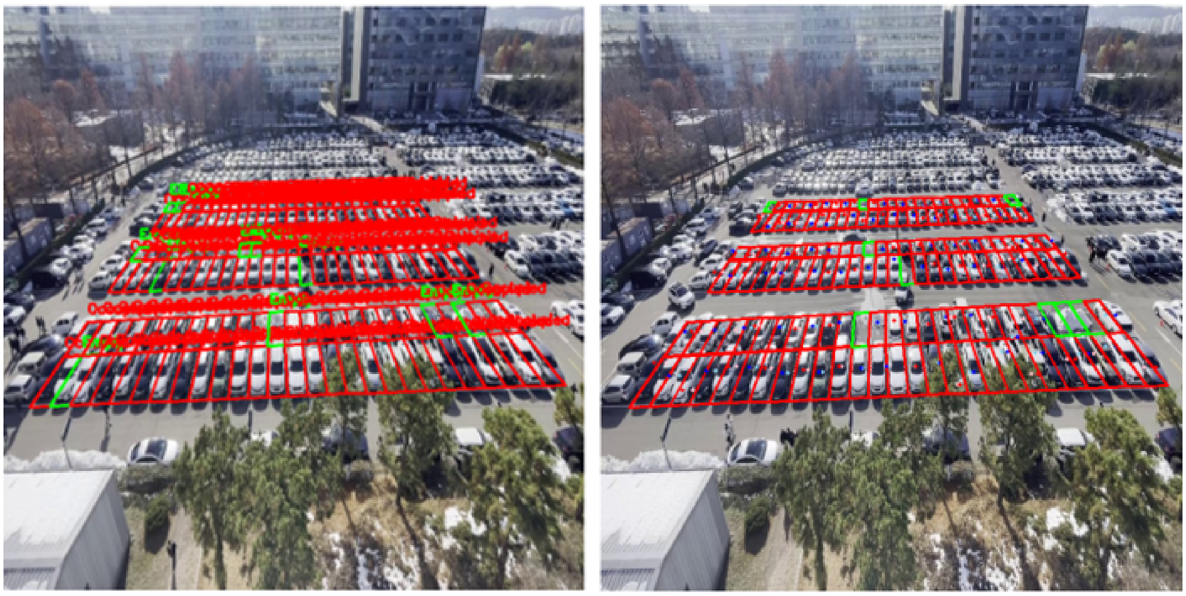

Figure 5: Adjusting the center points of the cars

3 Implementation

This section describes the implementation of the system, which consists of three main components: UI/UX, model, and the backend.

3.1 UI/UX

The parking lot in front of Sungkyunkwan University's Engineering Building 1 contains 486 parking spaces. Users must be able to check the occupancy status of each parking space through the user interface (UI). Since displaying all parking spaces on a single screen is not feasible, the spaces have been divided into two sectors, as shown in the figure below. Each parking space is represented using four colors: Grey, Green, Red, and Orange. These colors indicate the following statuses:

- **Grey**: Unknown (not visible)
- **Green**: vailable (empty)
- **Red**: Full (occupied)
- **Orange**: Tight (narrow space)

3.2 Model

To determine vehicle occupancy in each parking space, the YOLOv5 model was used. The entire parking lot is monitored by four cameras, and each camera's region is processed by a dedicated model. Each model holds coordinate information for the parking spaces assigned to its designated area. Frames are extracted from real-time video every 25 seconds, as this is the time required for the model to detect vehicles. The extracted frames are resized to 640 x 640, and the parking space coordinates are adjusted accordingly. The model then performs an initial vehicle detection using the resized frames. The center points of the detected bounding boxes are compared with the parking space coordinates to determine

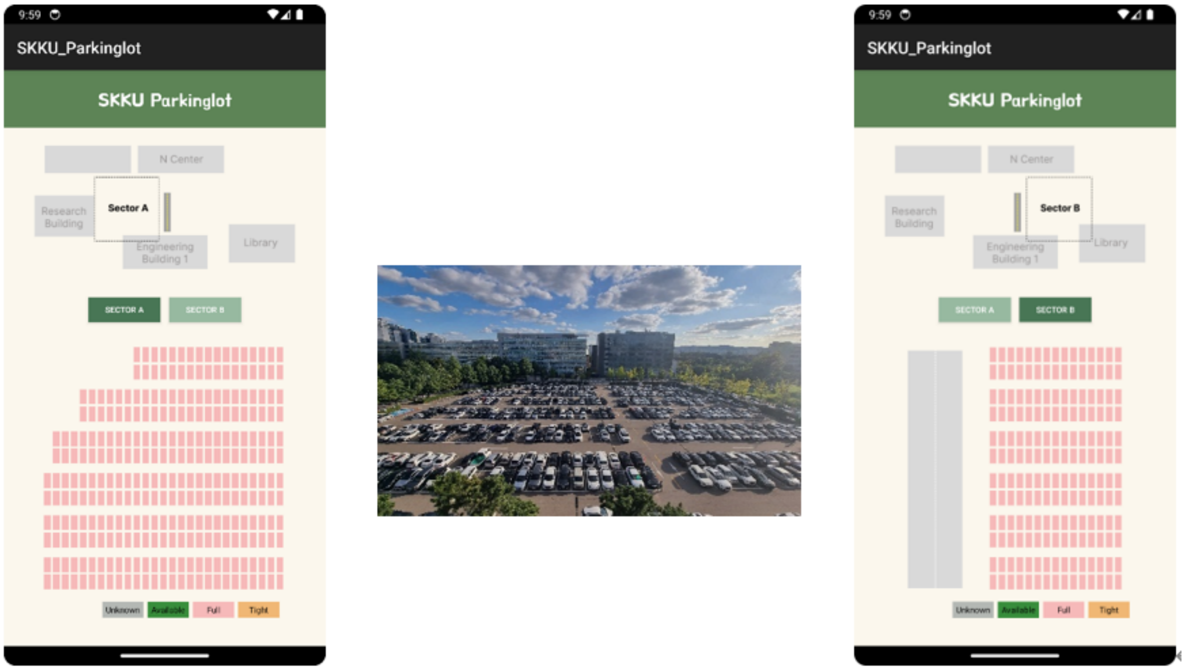

Figure 6: UI/UX

vehicle presence. To address the issue of low recall, an additional process is applied. For parking spaces initially detected as empty, the system extracts the asphalt color from spaces where no vehicles are present. It then checks the proportion of asphalt color within these spaces. If the proportion exceeds a predefined threshold, the space is classified as empty; otherwise, it is classified as occupied. The prediction data for parking spaces is sent to the database in the form of a dictionary. Each parking space ID is assigned a value: 0 for empty, 1 for occupied, and 2 for tight.

3.3 Database

The model updates the database values based on the transmitted data. The updated values are reflected in the application's user interface, allowing users to check the status of parking spaces in real time.

4 Evaluation

This section describes the overall system execution results, the model evaluation methods, and the corresponding evaluation outcomes. The evaluation is based on how accurately the system can detect empty parking spaces.

4.1 Demonstrate Results

Due to a malfunction in one camera, the demonstration was conducted using 3 out of 4 sectors. The system was executed while recording the parking lot for 5 minutes on December 3, 2024, at 11:50 AM. The system demonstrated high accuracy for individual frames, successfully capturing state changes when vehicles entered or exited parking spaces. However, an issue was observed where the state of certain parking spaces continued to fluctuate across consecutive frames, even when no vehicle movement occurred.

Figure 7: Detect Result

4.2 Evaluation Metrics Evaluation

4.2.1 mAP-50

mAP-50 is the metric used to evaluate the model's training results. The Average Precision (AP) value was calculated based on an overlap threshold where the bounding boxes of the actual object and the predicted object overlap by 50% or more.

	CARPK	**Truck dataset**
mAP-50	0.983	0.881

Table 2: mAP-50

4.2.2 Precision and Recall

Recall is a performance metric that indicates the proportion of actual positives correctly predicted by the model. Based on the system's results, it measures the percentage of actual empty parking spaces successfully detected by the model. This metric is important for evaluating how effectively the system can identify available parking spaces. Precision refers to the proportion of predicted positives that are actual positives. From the system's results, it represents the percentage of spaces predicted as empty that are genuinely vacant. This metric is crucial for assessing how accurately the system provides information to users. Accuracy is a performance metric that measures the proportion of correct predictions out of all predictions. Since users avoid parking spaces marked as occupied, true negatives are also meaningful to users. Results were derived using Sectors A, B and C. This result represents the model's vehicle detection accuracy. True refers to an actual vehicle, while Positive indicates that the model predicted the presence of a vehicle.

	TRUE	**FALSE**
Positive	378	3
Negative	13	7

TP	378	**Accuracy**	0.9601
TN	7	**Precision**	0.992126
FP	3	**Recall**	0.966752
FN	13	**F1**	0.979275

Table 3: Evaluation Result for Model

The following results represent the system's accuracy in detecting empty parking spaces. True refers to an actual empty parking space, while positive means that the model predicted the space as empty.

	TRUE	FALSE
Positive	7	13
Negative	3	378

TP	7	**Accuracy**	0.9601
TN	378	**Precision**	0.35
FP	13	**Recall**	0.7
FN	3	**F1**	0.466667

Table 4: Evaluation Result for System

4.3 Assess System

The model's vehicle detection accuracy was high, resulting in a high overall accuracy rate. However, we observed a low precision due to a high number of false positives. Additionally, snow accumulation in parking spaces at the time hindered the model's ability to accurately detect empty spots, leading to a lower recall score. As a result, while the application's accuracy in helping users find empty parking spaces may be somewhat limited, the high overall accuracy is sufficient for determining the general occupancy of the parking lot.

5 Limitations and Discussions

Our parking space detection system employs a hybrid algorithm combining YOLOv5 and color-based comparison to identify vacant spaces in real time. However, the system faces several limitations that could impact its performance and reliability.

1. **Accuracy Issues**: The hybrid approach can struggle with parking spaces located at the edges of the camera's field of view. YOLOv5 may find it challenging to accurately track these areas due to partial visibility or distortion. Additionally, when the color of a vehicle closely matches the road or parking lot surface, the system may misidentify an occupied space as vacant. This issue is particularly pronounced in cases where environmental conditions such as lighting or shadows obscure clear distinctions.

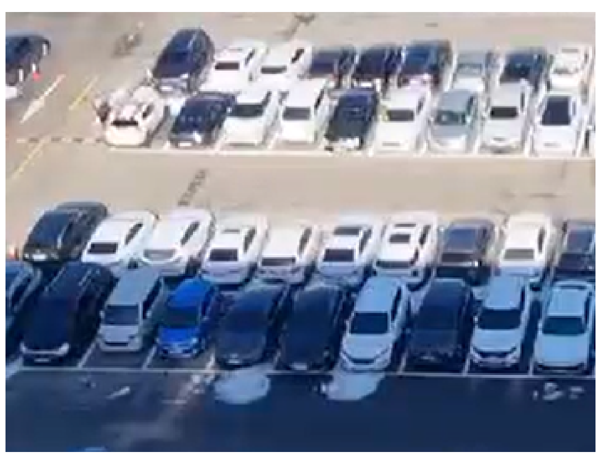

Figure 8: Accuracy Issues

2. **Unpredicted Objects**: Unexpected objects in the parking space, such as snow, debris, or other obstructions, can lead to incorrect detections. For instance, if snow covers a vacant space, the system may falsely identify it as available, creating confusion for users who cannot park there.

3. **Environmental Sensitivity**: The system's performance is affected by external environmental conditions. Snow-covered parking lots or heavy rain may interfere with both YOLOv5 and the

Figure 9: Unpredicted Objects

color extraction algorithm, reducing accuracy. Additionally, as the system is vision-based, it struggles to function effectively in low-light conditions or at night without sufficient lighting.

Figure 10: Environmental Sensitiviry

4. **Scalability and Resolution**: Although the current system supports a large-scale parking lot, resolution limitations can affect YOLOv5's ability to detect distant spaces accurately. Lower resolution images reduce the precision of object detection, especially for spaces located far from the camera.

Potential Solution: To address these limitations, the system could be enhanced with an additional AI model capable of recognizing unexpected objects in parking spaces. This could prevent misclassification caused by obstructions like snow or debris. Furthermore, increasing the resolution of camera feeds can extend YOLOv5's detection range and improve accuracy for spaces at the edges of the field of view. These enhancements, while outside the scope of the current implementation, are proposed as future work.

6 Related Work

In comparison to existing research, our project demonstrates several distinct advantages and contributions, particularly in its application to large-scale parking lots.

1. **Large-Scale Deployment**: Unlike many other projects that focus on small parking areas with fewer than 50 spaces, our system successfully manages a parking lot with 500 spaces using a multi-camera setup and a custom hybrid algorithm. This scalability is a significant achievement, highlighting the system's ability to handle large environments efficiently.

2. **Cost-Effectiveness**: While some existing studies rely on expensive multi-camera systems, we utilized low-cost alternatives such as smartphone-grade cameras without compromising accuracy.

This demonstrates the feasibility of deploying our system in a cost-sensitive context without sacrificing functionality.

3. **Novel Tightness Detection**: Our project also attempted to assess parking tightness—a feature not addressed in most related works. This functionality could help drivers identify not only available spaces but also those that are optimally suited for their vehicle size, thereby improving parking efficiency.

4. **Innovative Implementation**: Our project introduced functionalities that were previously unavailable in our school's parking system. The successful implementation of these features in a real-world environment further emphasizes the practical value and originality of our approach.

5. **Future Enhancements**: Building on existing research, our project also sets the stage for future improvements, such as integrating vehicle size detection and matching capabilities similar to those proposed in studies using YOLOv5. This would further refine the system's ability to optimize parking space usage.

By addressing these limitations and highlighting our advancements over prior works, our project demonstrates the potential for practical, scalable, and innovative solutions in parking space management.

7 Conclusion

The Parking Lot Vacancy Notification System successfully addresses critical challenges in parking space management by integrating innovative detection algorithms with user-centric design. Through strategic camera placement and fine-tuned detection models, the system provides real-time updates on parking availability, marking empty spaces, occupied spaces, and spaces near larger vehicles such as trucks. The use of a hybrid algorithm combining object detection and color analysis enhances detection accuracy, even in complex scenarios. Evaluation results demonstrated the system's high accuracy in identifying parking spaces, with robust performance metrics such as precision and recall, despite certain limitations like sensitivity to environmental conditions and resolution constraints. The deployment of an intuitive user interface further enriched the user experience by simplifying parking decisions and reducing stress associated with finding suitable spaces. However, challenges such as inaccuracies in edge detection, sensitivity to lighting variations, and the presence of unexpected objects in parking spaces were observed. These limitations underline opportunities for future improvements, including advanced object recognition for obstructions and the integration of higher-resolution cameras to enhance scalability and performance. By combining practical implementation with thoughtful innovation, the project establishes a new benchmark for large-scale parking management systems. It not only fills a significant gap in existing solutions but also lays the groundwork for future advancements, such as incorporating vehicle-specific recommendations and expanding adaptability across diverse environments. This project thus contributes to the growing need for smart and efficient parking solutions, offering a scalable and user-friendly approach to modern parking challenges.

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