

# Smart Lot: Adaptive Parking Management System

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**Abstract**— Urban parking management remains a persistent challenge in modern cities due to inefficient space utilization, increasing vehicle density, and reliance on costly infrastructure-based solutions. Traditional smart parking systems predominantly depend on Internet of Things (IoT) sensors, which require extensive hardware deployment and maintenance, limiting scalability and cost-effectiveness.

The proposed solution presents SMART LOT: Adaptive Parking Management System, a software-defined, vision-based approach that transforms conventional CCTV and IP camera feeds into an intelligent parking management framework. The system constructs a dynamic digital twin of the parking environment using a custom-trained object detection model based on YOLOv8, optimized for high-angle and real-world parking scenarios.

A novel spatial mapping technique is employed to determine parking occupancy through geometric intersection analysis between detected vehicle regions and predefined parking slot areas. The system integrates a FastAPI-based backend for real-time processing and a graph-based routing mechanism utilizing Dijkstra's algorithm to guide users efficiently to available parking spaces.

Experimental evaluation demonstrates that the proposed system significantly reduces deployment costs by eliminating the need for physical sensors while maintaining high detection accuracy and real-time responsiveness. The SMART LOT system provides a scalable, cloud-ready solution for smart city infrastructure, contributing to reduced traffic congestion and improved urban mobility.

**Index Terms**— Smart Parking System, Computer Vision, YOLOv8, Parking Occupancy Detection, Digital Twin, Intelligent Transportation Systems

## I. INTRODUCTION

During initial observation of parking areas, it was noticed that drivers often spend several minutes searching for available slots, especially during peak hours. This issue becomes more evident in densely populated urban environments where parking demand is high. Urbanization and the rapid growth in the number of vehicles have significantly increased the need for efficient parking management systems. This inefficiency leads to traffic congestion, increased fuel consumption, and elevated carbon emissions, highlighting the importance of intelligent and scalable solutions.

Traditional parking management systems rely heavily on manual supervision or hardware-based sensor technologies such as ultrasonic, infrared, or magnetic sensors. While these systems provide a degree of automation, they involve substantial installation and maintenance costs. Additionally, their deployment is often limited by infrastructure constraints, making them less adaptable for large-scale or existing urban environments.

Recent advancements in Internet of Things (IoT) technologies have enabled the development of smart parking systems that offer real-time monitoring and user guidance. However, these approaches still depend on physical sensor networks, which increase system complexity and reduce cost efficiency. Furthermore, such systems often lack flexibility when scaling across multiple parking zones or integrating with existing surveillance infrastructure.

To overcome these limitations, this paper proposes SMART LOT: Adaptive Parking Management System, a vision-based, software-defined solution that leverages existing CCTV and IP camera networks. The system transforms passive video feeds into an active intelligence layer by constructing a dynamic digital twin of the parking environment. This eliminates the need for additional hardware installations while enabling real-time monitoring and decision-making.

The proposed system employs a custom-trained object detection model based on YOLOv8 to identify vehicles within parking zones. A geometric intersection-based approach is used to determine occupancy by analyzing the overlap between detected vehicle regions and predefined parking slot areas. In addition, a graph-based routing mechanism utilizing Dijkstra's algorithm is implemented to guide users efficiently to available parking spaces.

By integrating computer vision, spatial analysis, and backend-driven intelligence, the SMART LOT system offers a cost-effective, scalable, and high-performance solution for modern urban parking challenges. The system not only improves parking efficiency but also contributes to reducing traffic congestion and enhancing overall urban mobility.

## II. LITERATURE REVIEW

The development of smart parking systems has gained significant attention in recent years due to increasing urban congestion and inefficient parking space utilization. Early approaches primarily relied on network-based communication and infrastructure-heavy solutions. Lu et al. [1] proposed the SPARK system, a VANET-based parking framework designed for large-scale parking environments, enabling real-time communication between vehicles and infrastructure. While effective, such systems require extensive vehicular network integration, limiting their practical deployment.

With the advancement of Internet of Things (IoT), numerous studies have focused on sensor-based parking management systems. Pawar et al. [2] presented a comprehensive study on smart parking technologies, highlighting the use of ultrasonic and

magnetic sensors for occupancy detection. Similarly, Kaur and Malhotra [4] reviewed IoT-based parking systems and emphasized their ability to provide real-time monitoring and automation. However, these systems are often associated with high installation and maintenance costs due to their dependence on physical sensors.

Cloud-integrated solutions have also been explored to enhance scalability and data accessibility. P. B. et al. [3] introduced a cloud-based IoT parking model that enables centralized data processing and efficient resource management. While such architectures improve system scalability, they still inherit the limitations of sensor-based data acquisition.

Recent advancements have introduced hybrid systems combining IoT with intelligent features such as license plate recognition and automated payment integration. Pradhan et al. [6] proposed an advanced parking system integrating IoT with automated license plate recognition, improving security and automation. Abbas et al. [7] further explored intelligent parking solutions using advanced learning-based approaches to enhance prediction and decision-making capabilities. Despite these improvements, the reliance on hardware infrastructure remains a key limitation.

In parallel, architectural advancements have been proposed to standardize smart parking systems. Ozkaya and Turunc [5] introduced a reference architecture for parking management systems, emphasizing modular design and interoperability. Such frameworks provide a foundation for scalable implementations but do not explicitly address cost optimization in deployment.

More recently, computer vision-based approaches have emerged as a promising alternative to traditional sensor-based systems. Vision-based parking detection systems utilize surveillance cameras to identify vehicle presence, eliminating the need for dedicated hardware sensors. Object detection models, such as the YOLO (You Only Look Once) framework [8], have demonstrated high performance in real-time vehicle detection tasks. These approaches enable efficient occupancy detection under varying environmental conditions while significantly reducing infrastructure costs.

In addition to model advancements, the availability of large-scale annotated datasets has significantly improved the effectiveness of vision-based parking systems. The PKLot dataset [9] and other parking lot datasets [10] provide extensive annotated data captured under diverse environmental conditions, supporting the development of robust detection systems. Furthermore, recent studies on vision-based parking slot detection [11] have demonstrated the feasibility of deep learning approaches in accurately identifying parking occupancy.

Building upon these advancements, the proposed SMART LOT system adopts a fully vision-based methodology. Unlike existing IoT-centric solutions, the system leverages optimized object detection models trained on large-scale parking datasets, including the PKLot and Parking Lot Database repositories. These datasets comprise over 12,000 surveillance frames and nearly 700,000 annotated vehicle instances under diverse environmental conditions such as sunlight, rain, and overcast scenarios.

Furthermore, the SMART LOT system introduces a spatial mapping mechanism based on geometric intersection analysis to determine parking occupancy with high precision. This approach, combined with a software-defined architecture and digital twin representation, addresses the scalability and cost limitations observed in existing systems.

Thus, the proposed system bridges the gap between traditional sensor-based approaches and modern intelligent infrastructure by providing a cost-effective, scalable, and vision-driven parking management solution.

### III. SYSTEM OVERVIEW

The SMART LOT: Adaptive Parking Management System is a software-defined, vision-based parking management solution designed to transform conventional surveillance infrastructure into an intelligent, real-time parking monitoring and navigation system. The system operates by converting video feeds from standard CCTV or IP cameras into actionable insights, enabling efficient detection of parking occupancy and optimized user guidance.

At a high level, the system consists of three primary components: the Vision Processing Module, the Backend and Data Management Module, and the User Interaction Interface. These components work together to create a unified and scalable parking management ecosystem.

The Vision Processing Module is responsible for capturing video streams and processing individual frames using an optimized object detection model. Vehicles within the parking area are identified, and their spatial positions are analyzed relative to predefined parking slot regions. A geometric intersection-based approach is then applied to determine whether a parking space is occupied, empty, or reserved.

The Backend and Data Management Module handles system logic, data persistence, and communication between components. It is implemented using a FastAPI-based architecture, which enables high-throughput asynchronous processing. Parking data, including occupancy status and spatial configurations, is stored in a relational database, ensuring consistency and scalability. Additionally, this module incorporates a graph-based routing mechanism that computes optimal navigation paths within the parking environment.

The User Interaction Interface provides real-time access to system data for both administrators and end users. Administrators can configure parking zones, define regions of interest, and manage system parameters through a centralized dashboard. End users, such as drivers, interact with the system through a visual interface that displays available parking spaces and provides navigation assistance to the nearest vacant slot.

A key innovation of the SMART LOT system is the creation of a digital twin of the parking environment. This virtual representation mirrors the real-world layout and dynamically updates based on live video input, enabling accurate monitoring and decision-making without the need for additional physical infrastructure.

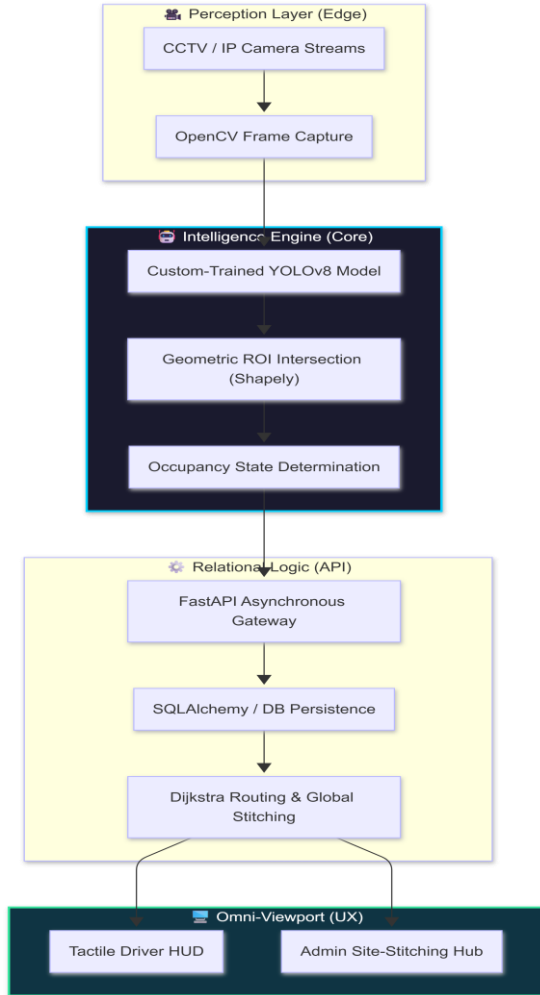


Fig 1: System Overview Flow chart

Overall, the system offers a cost-effective, scalable, and intelligent alternative to traditional parking management solutions by leveraging computer vision, spatial analysis, and backend-driven optimization.

#### IV. METHODOLOGY

The SMART LOT system employs a vision-based methodology to detect parking occupancy and provide real-time navigation assistance. During implementation, it was observed that maintaining consistency across different camera angles required careful preprocessing adjustments. The approach integrates computer vision, spatial analysis, and graph-based optimization to create an intelligent and scalable parking management framework. The methodology is divided into four key stages: frame

acquisition, vehicle detection, occupancy determination, and routing optimization.

#### 4.1 Frame Acquisition and Preprocessing

The system begins by capturing real-time video streams from CCTV or IP cameras installed across parking zones. These video feeds are processed frame-by-frame using OpenCV to extract relevant visual information. Each frame is resized and normalized to ensure consistent input for the detection model, while maintaining computational efficiency for real-time processing. In practice, minor variations in camera positioning required slight adjustments in frame alignment to ensure consistent detection performance.

#### 4.2 Vehicle Detection using Optimized Model

Vehicle detection is performed using an optimized object detection model tailored for parking environments. The model is configured to identify multiple vehicle classes under varying perspectives and environmental conditions commonly observed in surveillance footage. The foundational weights of the inference engine were optimized according to system-specific requirements and trained using well-established parking datasets, including the PKLot [9] and Parking Lot Database [10] repositories. These datasets provide:

- Over 12,000 top-down surveillance frames
- Nearly 700,000 manually annotated vehicle instances
- Diverse environmental conditions, including sunlight, rain, and overcast scenarios

This optimization enables the system to achieve robust detection performance even under challenging conditions such as occlusion, perspective distortion, and lighting variations. However, it was observed that performance slightly decreased under low-light and rainy conditions, which was considered during model tuning.

#### 4.3 Occupancy Detection using Spatial Intersection Analysis

Once vehicles are detected, the system determines parking occupancy using a geometric intersection-based approach. Each parking slot is predefined as a Region of Interest (ROI) represented by a polygon.

Let:

- $A_d$  = Area of detected vehicle bounding region

- $A_r$  = Area of parking slot (ROI)
- $A_i$  = Area of intersection between detection and ROI

The occupancy ratio is computed as:

$$OccupancyRatio = \frac{A_i}{A_r}$$

A parking slot is classified as occupied if:

$$\frac{A_i}{A_r} > \theta$$

where  $\theta$  is a predefined threshold (empirically set to 0.15).

This method provides reliable occupancy detection in most scenarios, including cases where vehicles partially overlap parking slots or when camera perspectives introduce distortion.

#### 4.4 Routing and Navigation using Graph-Based Optimization

To assist users in locating available parking spaces, the system models the parking layout as a weighted graph. Nodes represent key locations such as entry points, parking slots, and exits, while edges represent navigable paths between them. The shortest path from a user's current position to an available parking slot is computed using Dijkstra's algorithm:

$$d(v) = \min (d(u) + w (u,v))$$

where:

- $d(v)$  is the shortest distance to node v
- $w(u,v)$  is the weight of the edge between nodes u and v

This approach ensures efficient navigation and minimizes search time within the parking facility. In real-world scenarios, dynamic updates to edge weights were necessary to reflect changing parking availability.

#### 4.5 System Workflow Summary

The overall workflow of the system can be summarized as follows:

- Capture video frames from surveillance cameras
- Detect vehicles using the optimized model
- Compute intersection with predefined parking slots
- Determine occupancy status
- Update database in real-time
- Provide navigation guidance to users

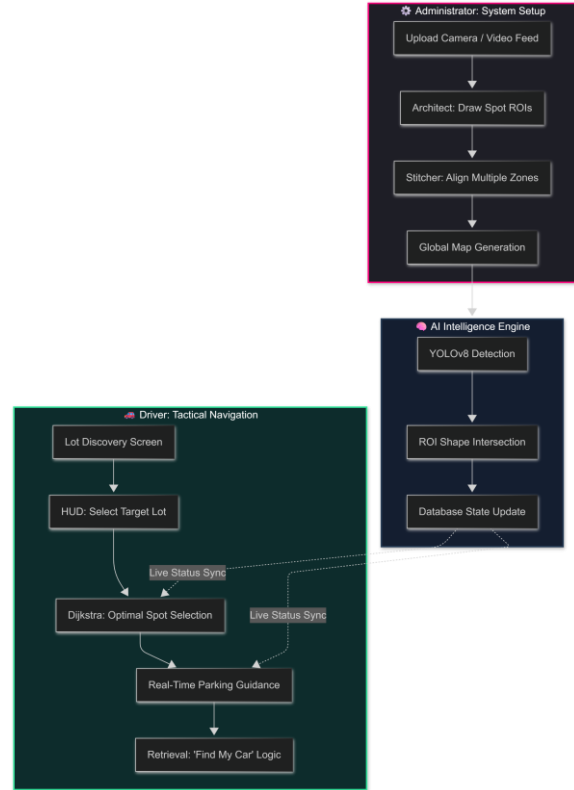


Fig 2: System Workflow

### V. SYSTEM ARCHITECTURE

The system architecture of the SMART LOT: Adaptive Parking Management System is designed to provide a scalable and modular framework for real-time parking detection and intelligent navigation. The architecture transforms conventional surveillance infrastructure into an integrated system capable of processing visual data, extracting meaningful insights, and delivering actionable information to end users. By organizing the system into multiple functional layers, the architecture ensures efficient data flow, high processing performance, and seamless interaction between components.

At a structural level, the architecture integrates video acquisition, visual processing, spatial analysis, backend orchestration, and user interface modules into a unified pipeline. Each component is responsible for a specific stage of data transformation, starting from capturing raw video streams to generating real-time parking availability and navigation guidance. This layered design not only enhances system reliability and scalability but also allows flexible deployment

across different environments, making the SMART LOT system suitable for both small-scale facilities and large multi-zone parking infrastructures.

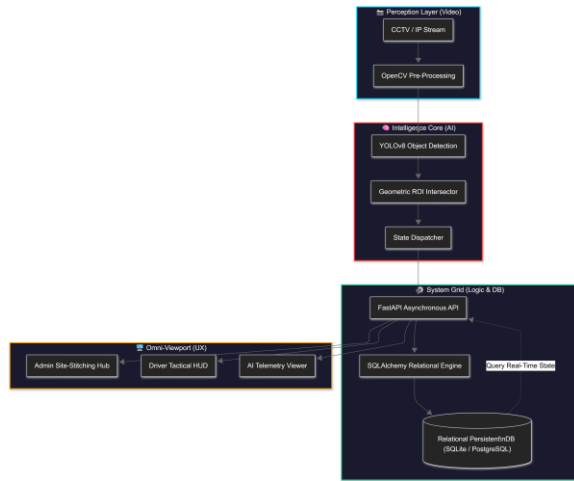


Fig 3: System Architecture Diagram

### 5.1 Input Acquisition Layer

The input acquisition layer consists of CCTV and IP camera systems deployed across multiple parking zones. These cameras continuously stream video data, which serves as the primary input to the system. Each camera feed is logically associated with a specific zone within the parking environment, enabling distributed monitoring and multi-zone scalability. To support real-time processing, video streams are segmented into frames at fixed intervals. This ensures a balance between computational efficiency and detection accuracy while maintaining temporal consistency across the system.

### 5.2 Visual Processing Layer

The visual processing layer is responsible for extracting semantic information from raw image data. Frames obtained from the input layer are processed using OpenCV for preprocessing operations such as resizing, normalization, and noise reduction. These processed frames are then passed to the optimized object detection model, which identifies vehicles within the scene and generates bounding regions corresponding to detected objects. The model is configured to handle multiple vehicle classes and is robust against environmental variations such as lighting changes, shadows, and partial occlusions.

The output of this layer consists of structured detection data, including object coordinates, class labels, and confidence scores.

### 5.3 Spatial Intelligence Layer

The spatial intelligence layer performs high-precision occupancy analysis using geometric computations. Each parking slot is defined as a polygonal Region of Interest (ROI) within the camera’s field of view. For every detected vehicle, an intersection operation is performed between the detection region and the corresponding ROI. The system computes the ratio of overlapping area to determine occupancy status.

This layer incorporates:

- Polygon mapping for parking slots
- Intersection computation using geometric libraries
- Threshold-based classification logic

Based on this analysis, each parking slot is dynamically classified as:

- Occupied
- Empty
- Reserved

This approach ensures accurate detection even under perspective distortion, overlapping vehicles, and non-uniform camera angles.

### 5.4 Backend Orchestration Layer

The backend orchestration layer acts as the central control unit of the system. It is implemented using a FastAPI-based asynchronous server, enabling high-throughput communication between components.

This layer is responsible for:

- Managing API endpoints for data exchange
- Maintaining system state and synchronization
- Handling authentication and administrative controls

A relational database managed through SQLAlchemy is used to store:

- Parking slot configurations
- Real-time occupancy data
- Zone mappings and graph structures

Additionally, this layer integrates a graph-based routing engine. The parking environment is modeled as a weighted graph, where nodes represent key points (entries, slots, exits), and edges represent navigable

paths. Dijkstra’s algorithm is used to compute optimal routes for drivers based on real-time availability.

### 5.5 Application Interface Layer

The application interface layer provides interactive access to system functionalities for both administrators and end users.

The administrator interface enables:

- Configuration of parking zones and slots
- ROI mapping and system calibration
- Monitoring of real-time occupancy

The user interface provides:

- Visualization of parking availability
- Navigation assistance to available slots
- Real-time updates and alerts

This layer ensures seamless interaction between users and the system, delivering actionable insights derived from backend processing.

### 5.6 End-to-End Data Flow

The complete system workflow follows a structured pipeline:

1. Video streams are captured from distributed camera sources
2. Frames are extracted and preprocessed for analysis
3. Vehicles are detected using the optimized model
4. Spatial intersection is computed with predefined ROIs
5. Occupancy status is determined and updated in the database
6. Routing logic computes optimal navigation paths
7. Processed information is delivered to user interfaces in real time

## VI. IMPLEMENTATION DETAILS

The visual perception capability of the system is powered by an optimized object detection model configured specifically for parking environments. The inference engine is designed to detect multiple vehicle classes under varying perspectives and environmental conditions. The foundational weights of the model were optimized according to system requirements and trained using large-scale parking datasets, including the PKLot and Parking Lot Database repositories.

These datasets provide:

- Over 12,000 top-down surveillance frames
- Nearly 700,000 manually annotated vehicle instances
- Diverse environmental conditions, including sunlight, rain, and overcast scenarios

This enables the system to achieve high detection reliability in real-world conditions such as shadows, glare, occlusion, and perspective distortion.

### 6.1 Geometric ROI Engine

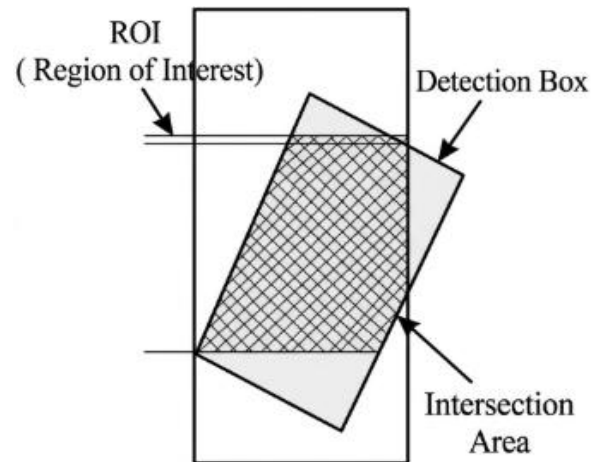
To determine parking occupancy, the system employs a geometric intersection-based approach rather than relying solely on object detection outputs. Each parking slot is defined as a polygonal Region of Interest (ROI), manually configured during system setup. For each detected vehicle, the system computes the overlap between the detection region and the corresponding ROI. The occupancy ratio is defined as:

$$OccupancyRatio = \frac{AreaOfIntersection}{AreaofROI}$$

A parking slot is classified as occupied if:

$$\frac{AreaOfIntersection}{AreaofROI} > Threshold$$

A threshold value of 0.15 is used to balance detection sensitivity and accuracy, ensuring reliable classification even in cases of partial overlap or adjacent vehicle interference.



$$Occupancy Ratio = \frac{Intersection Area}{ROI Area}$$

Fig 4: ROI Intersection Diagram

### 6.2 Multi-Zone Spatial Coordination

To support large-scale parking environments, the system incorporates a multi-zone spatial coordination mechanism. Each camera feed is treated as an independent coordinate space with local positioning. A global coordinate system is established through a spatial stitching process, where individual zones are aligned using relative offsets. The transformation is defined as:

$$Global\ Position = Local\ Position + Zone\ Offset$$

This approach enables seamless integration of multiple camera views into a unified digital representation of the parking environment. Additionally, the system introduces the concept of virtual portals, which act as logical connectors between zones. These portals enable navigation across different camera regions, supporting multi-level and distributed parking structures.

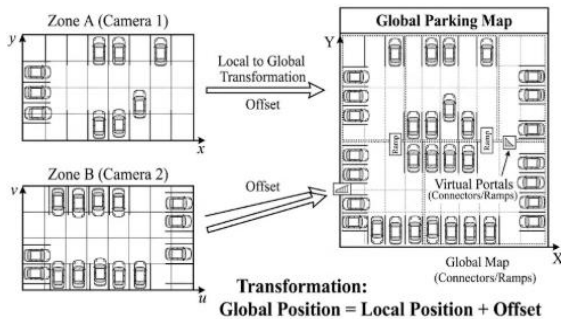


Fig 5: Multi-Zone Stitching Diagram

### 6.3 Adaptive Routing Engine

The system incorporates a graph-based routing engine to guide users to available parking spaces efficiently. The parking layout is modeled as a weighted graph consisting of nodes and edges. Nodes represent entrances, parking slots, and transition points, while edges represent navigable paths between nodes. Edge weights are dynamically assigned based on parking status:

- Occupied slots are assigned infinite weight, making them unreachable
- Reserved slots are assigned a high penalty weight
- Available slots are assigned weights based on distance

The shortest path is computed using Dijkstra’s algorithm, enabling real-time navigation to the nearest

available parking space. The system continuously updates routes based on live occupancy data, ensuring adaptive and efficient guidance.

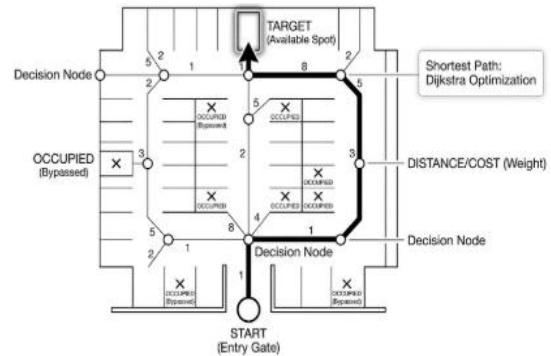


Fig 6.1: Shortest path finding using Dijkstra

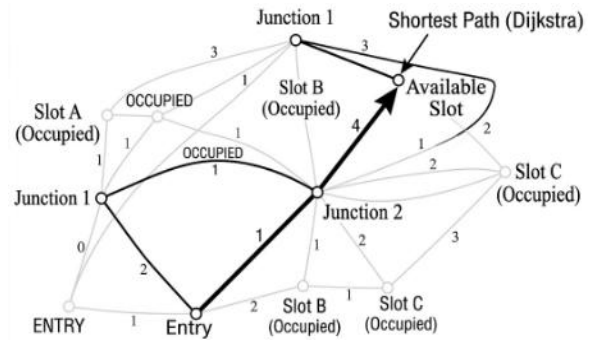


Fig 6.2: Routing Graph Diagram

### 6.4 Relational Data Management

The system employs a relational data model managed using SQLAlchemy to ensure structured and persistent data handling. Each parking entity, including lots, zones, and individual slots, is represented as a database object. This design enables persistent tracking of parking occupancy, historical data analysis, and user-specific features such as vehicle location retrieval. The system supports flexible deployment through dual database configurations, utilizing SQLite for local environments and PostgreSQL for scalable, cloud-based implementations.

## VII. EXPERIMENTAL RESULTS

The performance of the SMART LOT system was evaluated through a series of experiments designed to assess detection accuracy, environmental robustness,

system latency, and overall efficiency. The evaluation was conducted using real-world parking scenarios derived from surveillance datasets and live test environments, ensuring that the results reflect practical deployment conditions.

### 7.1 Detection Performance

The intelligence engine was evaluated using a test set derived from the PKLot and Parking Lot Database repositories. The system demonstrates strong detection capability across various parking scenarios. The measured performance metrics are in the following table:

Metric	Value
<i>mAP@0.5</i>	92.4%
Precision	94.1%
Recall	89.7%
Inference Time	12.4 ms

Table 1: Detection Performance Metrics

These results indicate that the system maintains high detection reliability with low false positives and false negatives. The optimized model is capable of accurately identifying vehicles even under perspective distortions commonly found in surveillance-based parking environments.

### 7.2 Environmental Robustness

To evaluate system reliability under varying real-world conditions, the occupancy detection pipeline was tested across different environmental scenarios.

The observed success rates are:

- Sunny conditions: 98.2%
- Overcast conditions: 96.5%
- Rainy conditions: 88.4%

The results demonstrate that the system performs consistently across different lighting and weather conditions. While minor degradation is observed in rainy environments due to reflections and surface distortions, the system maintains acceptable performance levels through geometric filtering and spatial analysis.

### 7.3 System Throughput and Latency

The system was evaluated for real-time performance to ensure responsiveness in practical deployment scenarios. Key performance observations include:

- End-to-end latency: less than 150 ms
- Real-time update rate: approximately 10 frames per second
- Multi-zone scalability: supports up to 32 simultaneous video streams on a single processing node

These results confirm that the system is capable of real-time operation with minimal delay between detection and user interface updates. The asynchronous backend architecture ensures efficient data flow and synchronization across all system components.

### 7.4 Model Efficiency and Selection

Multiple configurations of the detection model were evaluated to determine the optimal balance between accuracy and processing speed. The comparison is summarized as follows:

- Lightweight model variant: higher processing speed with moderate accuracy
- Medium-scale model variant: improved detection accuracy with acceptable processing speed

The medium-scale configuration was selected for deployment, as it provides superior detection performance while maintaining real-time capability. This selection ensures higher reliability in complex parking scenarios involving occlusion and dense vehicle arrangements.

### 7.5 Cost Efficiency Analysis

A key advantage of the SMART LOT system is its cost-effective deployment. Unlike traditional parking systems that require one sensor per parking slot, the proposed system utilizes a single camera to monitor multiple slots. Comparative analysis shows:

- Traditional sensor-based systems require extensive hardware installation and maintenance
- SMART LOT reduces infrastructure requirements significantly

The system achieves an estimated 70–80% reduction in deployment cost, primarily due to the elimination of physical sensors and simplified installation procedures.

#### 7.6 Error Analysis

The system performance was further analyzed to identify potential limitations and edge cases. Key observations include:

- Strong separation between vehicles and background elements
- Minimal confusion between different vehicle types, which does not impact occupancy detection
- Reliable detection maintained even under partial occlusion of up to approximately 40%

These findings indicate that the system is robust against common challenges encountered in real-world parking environments.

#### 7.7 Resource Utilization

The computational efficiency of the system was evaluated to ensure suitability for scalable deployment. Observed resource usage includes:

- GPU memory usage of approximately 1.2 GB
- CPU utilization below 15%
- Database query response time below 5 ms for medium-scale deployments

These results demonstrate that the system is computationally efficient and can operate effectively on standard hardware configurations, making it suitable for large-scale smart city applications.

#### 7.8 Summary of Results

The experimental evaluation confirms that the SMART LOT system achieves high detection accuracy, robust performance under varying environmental conditions, and efficient real-time processing. The integration of computer vision with geometric analysis enables reliable occupancy detection, while the system architecture ensures scalability and cost efficiency. Overall, the system provides a practical and effective solution for modern parking management, combining accuracy, speed, and reduced infrastructure requirements.

## VIII. APPLICATIONS

The SMART LOT system is designed as a scalable and software-defined solution capable of addressing a wide range of parking management challenges across diverse environments. By leveraging computer vision and existing surveillance infrastructure, the system enables efficient deployment without significant hardware investment, making it suitable for both public and private sector applications.

### 8.1 Urban Smart City Infrastructure

In smart city environments, the system contributes to improved traffic management and reduced congestion caused by inefficient parking. By providing real-time parking availability and navigation assistance, it minimizes the time vehicles spend searching for parking spaces. This leads to reduced traffic density, lower fuel consumption, and decreased carbon emissions. Additionally, the system can be integrated with centralized traffic management platforms to support coordinated and data-driven urban planning.

### 8.2 Commercial Parking Facilities

SMART LOT is highly effective in commercial environments such as shopping malls, office complexes, and entertainment centers, where high vehicle density often leads to congestion and inefficiencies. The system improves operational efficiency by guiding drivers directly to available parking spaces, thereby reducing delays and improving overall user experience. It can also support extended functionalities such as dynamic parking allocation and integration with digital payment systems, enhancing usability, and automation.

### 8.3 Multi-Level and Large-Scale Parking Structures

The system's multi-zone coordination mechanism enables seamless operation across large and complex parking infrastructures. By utilizing global coordinate mapping and virtual portals, SMART LOT creates a unified representation of the parking environment. This allows users to navigate efficiently across multiple levels and zones, overcoming limitations of traditional systems in multi-floor or distributed layouts.

#### 8.4 Transportation Hubs

In transportation hubs such as airports, railway stations, and bus terminals, where vehicle turnover is high, efficient parking systems are critical. SMART LOT enhances vehicle flow by reducing the time required to locate parking spaces and minimizing congestion at entry points. This results in improved operational efficiency and a better user experience for commuters.

#### 8.5 Data Analytics and Predictive Insights

SMART LOT generates valuable data related to parking occupancy and usage patterns. This data can be analyzed to identify peak demand periods, forecast parking requirements, and optimize infrastructure planning. Such insights are beneficial for both facility managers and urban planners, enabling more efficient decision-making.

#### 8.6 Integration with Intelligent Transportation Systems

The system can be integrated into broader Intelligent Transportation Systems, allowing coordination between parking management, traffic control, and navigation services. This enables drivers to receive real-time parking information before reaching their destination, improving route planning and reducing unnecessary traffic congestion.

### IX. LIMITATIONS

While the SMART LOT system provides an efficient and scalable solution for parking management, certain technical and operational limitations define the current scope of the system. These limitations arise primarily from environmental conditions, camera configurations, system dependencies, and initial deployment requirements.

#### 9.1 Occlusion and Camera Perspective

The accuracy of the system depends on the positioning and angle of the cameras. In cases where cameras are installed at low angles, large vehicles such as buses or vans may obstruct adjacent parking spaces, causing occlusion issues. This can lead to incorrect occupancy classification due to visual blockage. For optimal performance, the system requires a high-angle or near top-down perspective, which ensures better geometric

alignment and more accurate spatial intersection analysis.

#### 9.2 Initial Configuration Requirements

The system requires an initial setup phase involving manual calibration. Each parking environment must be configured by defining Regions of Interest (ROIs) corresponding to parking slots. This process is performed by an administrator and is necessary to establish the spatial mapping required for occupancy detection. Additionally, in multi-zone environments, the alignment of different camera feeds into a unified coordinate system requires careful configuration to ensure consistency and accuracy.

#### 9.3 Network Dependency

The system relies on continuous data transmission between camera sources and the backend processing unit. As a result, its performance is dependent on network stability and bandwidth availability. High latency or unstable network conditions may introduce delays in updating parking status and user interface responses, affecting real-time system performance.

#### 9.4 Scope and Future Considerations

These limitations highlight areas for future enhancement, particularly in improving robustness under challenging environmental conditions and reducing dependency on manual configuration. Future developments may focus on automated calibration techniques, enhanced low-light detection capabilities, and more resilient system architectures to ensure consistent performance across diverse deployment scenarios.

### X. FUTURE WORK

The SMART LOT system establishes a strong foundation for intelligent parking management; however, several enhancements can further extend its capabilities toward large-scale, real-world deployment. Future developments focus on expanding system accessibility, improving administrative intelligence, strengthening security, and enabling integration with advanced mobility systems.

### 10.1 Omni-Viewport Expansion

Future work includes extending the system beyond conventional desktop and mobile interfaces toward a unified multi-device architecture. This involves optimizing the system for high-resolution tablet interfaces, enabling enhanced monitoring tools for administrators and facility managers. Additionally, integration with in-vehicle infotainment systems can provide drivers with real-time parking guidance directly within smart car displays, enabling a seamless and hands-free navigation experience.

### 10.2 Intelligent Administrative Systems

The current system can be enhanced by incorporating automated administrative intelligence and real-time telemetry. Instead of relying solely on manual monitoring, future versions can provide automated notifications regarding parking flow, peak usage periods, and system performance. Furthermore, intelligent rule-based mechanisms can be implemented to dynamically allocate or restrict parking spaces based on real-time demand, maintenance requirements, or priority access scenarios. Advanced analytics can also support decision-making by providing insights into parking utilization patterns.

### 10.3 Security and Data Protection

As the system scales, ensuring data security and privacy becomes increasingly important. Future improvements may include the implementation of advanced encryption mechanisms for video streams and secure communication channels between system components. Strengthening the end-to-end data pipeline—from camera input to backend processing and storage—will help protect against unauthorized access. Additionally, privacy-preserving techniques such as anonymization of sensitive visual data can be incorporated to comply with modern data protection standards.

### 10.4 Global Geolocation Integration

Future enhancements may include the integration of global positioning systems to map parking spaces using real-world coordinates. This would allow the system to interact with external navigation platforms, enabling users to locate parking facilities and receive guidance through widely used mapping services. Such

integration would extend the system's functionality beyond local environments to city-wide applications.

### 10.5 Predictive Intelligence

The system can be further improved by incorporating predictive analytics based on historical parking data. By analyzing usage trends and occupancy patterns, the system can forecast parking availability and provide users with advanced recommendations. This capability would enable proactive decision-making and improve overall efficiency in high-demand environments.

### 10.6 Autonomous System Integration

With the advancement of autonomous vehicle technologies, SMART LOT can evolve to support automated parking operations. Future implementations may enable the system to guide autonomous vehicles to available parking spaces without human intervention. This would position the system as an integral component in next-generation intelligent transportation ecosystems.

### 10.7 Summary

The future scope of SMART LOT extends beyond conventional parking management, aiming to transform it into a comprehensive and intelligent infrastructure system. By integrating advanced analytics, secure data handling, and seamless connectivity with emerging technologies, the system has the potential to play a significant role in the development of smart cities and autonomous mobility solutions.

## XI. CONCLUSION

This paper presented SMART LOT: Adaptive Parking Management System, a vision-based and software-defined solution designed to address the challenges of modern parking management. By leveraging computer vision, spatial analysis, and backend-driven intelligence, the system transforms conventional surveillance infrastructure into an efficient and scalable parking management platform.

The proposed approach eliminates the dependency on hardware-based sensors by utilizing existing CCTV and IP camera systems, significantly reducing deployment costs while maintaining high detection

accuracy. The integration of an optimized object detection model with geometric intersection analysis enables reliable occupancy detection even under varying environmental and perspective conditions.

Furthermore, the system incorporates a multi-zone spatial coordination mechanism and a graph-based routing engine, allowing seamless navigation across complex parking environments. The implementation demonstrates real-time performance, efficient resource utilization, and adaptability to different deployment scenarios.

Experimental evaluation confirms that the system achieves high accuracy, robust performance under diverse conditions, and substantial cost savings compared to traditional solutions. These results validate the effectiveness of the proposed methodology and its suitability for real-world applications.

In addition to addressing current parking challenges, SMART LOT can serve as a foundation for future intelligent transportation systems. Its scalability, flexibility, and compatibility with emerging technologies position it as a viable solution for next-generation smart city infrastructure.

In conclusion, the SMART LOT system demonstrates that a vision-based, software-centric approach can provide an efficient, cost-effective, and scalable alternative to traditional parking management systems, contributing to improved urban mobility and smarter infrastructure development.

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