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Vehicle Parking Slot Vacancy Detection Using Machine Learning

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Abstract: Urbanization has significantly increased vehicle density in cities, intensifying the demand for intelligent parking systems. This project introduces a real-time Parking Slot Vacancy Detection system utilizing computer vision and the Mask R-CNN model to identify and segment occupied and vacant parking slots from live video feeds. The system defines parking slot boundaries and uses deep learning for instance-level object detection. It provides a user-friendly web interface for real-time monitoring and slot booking. The solution is scalable, adaptable to various environments, and integrates easily with existing surveillance infrastructure—supporting smarter urban mobility and sustainable traffic management.

Key Words: Parking Slot Detection, Mask R-CNN, Machine Learning, Computer Vision, Real-Time Monitoring, Smart City

1.INTRODUCTION

In recent years, the rapid growth in the number of vehicles has created significant challenges in urban areas, particularly related to parking space management. Drivers often spend considerable time searching for vacant slots, which contributes to increased traffic congestion, fuel consumption, and environmental pollution. Traditional parking systems, such as manual checks or sensor-based monitoring, are either inefficient or costly, especially in large-scale or outdoor environments.

To address these limitations, machine learning and computer vision techniques have emerged as promising alternatives. By using camera footage and automated algorithms, parking slot occupancy can be detected in real-time without the need for physical sensors. This approach not only reduces operational costs but also enables scalable and flexible solutions for smart city applications.

This project proposes a system that utilizes Convolutional Neural Networks (CNNs) to analys e images of parking lots and determine slot availability. The model is trained using publicly available datasets and integrated into a web-based interface for real-time monitoring. The system is designed to be accurate, cost-effective, and easy to deploy in public or private parking infrastructures.

2. Body of Paper

2.1 Literature Review

Several researchers have explored parking automation using image processing, sensors, and CNNs:

- Geng and Cassandras proposed wireless sensor networks for smart parking, which, despite accuracy, required costly installations.
- Amato et al. utilized CNNs for decentralized parking detection but lacked real-time visual output.
- Huang et al. implemented YOLO for object detection in parking lots with high speed and accuracy but with challenges in segmentation.

These studies contributed significantly to parking systems development but highlighted a need for a scalable, real-time, and cost-efficient solution. This paper addresses that need using **Mask R-CNN** for accurate vehicle segmentation without physical sensors.

2.2 Machine Learning For Parking Detection

The core component of the system is Mask R-CNN, a deep learning architecture capable of object detection and instance segmentation in a single framework. It employs:

- ResNet as a feature extraction backbone
- Region Proposal Network (RPN) for locating potential objects
- Segmentation masks and bounding boxes for vehicle localization

The model was trained using thousands of parking lot images annotated as "vacant" or "occupied." Upon

deployment, it receives video frames, processes each in real-time, and overlays classification outputs, allowing the UI to reflect the status instantly.

2.3 Tools And Libraries

To build an efficient, portable, and user-friendly system, the following tools and technologies were used:

- **Languages**: Python
- **Libraries**: OpenCV (image capture and preprocessing), TensorFlow & Keras (model implementation), NumPy & Pickle (slot region storage)
- **Model**: Mask R-CNN with ResNet101 backbone
- **Framework**: Flask for API and UI backend integration
- **Frontend**: HTML, CSS, JavaScript, and Bootstrap for a responsive interface
- **Visualization**: Matplotlib and Plotly to generate interactive graphs and heatmaps

2.4 Research Gap And Contribution :

Gap Identified:

- Sensor-based systems require installation and maintenance.
- Image-based systems lack accurate instance segmentation or real-time feedback.

Contribution:

- Real-time slot classification using only **camera feeds**
- No need for physical infrastructure or high-end hardware
- Supports mobile/desktop access with a responsive UI
- Visual analytics for smart management (occupancy trends, heatmaps)
- Integration-ready with smart city platforms or commercial parking lots

3.Methodology

This section elaborates on the sequential development of the proposed **Parking Slot Vacancy Detection System using Machine Learning**. The methodology is divided into six core components: **data acquisition**, **data preprocessing**, **defining parking slots**, **model implementation**, **system integration**, and **result visualization**.

3.1 Data Acquisition

The system begins by acquiring video feeds from surveillance cameras strategically installed in parking lots. These feeds capture continuous footage of vehicle movement and parking slot availability. The cameras are capable of capturing **high-resolution frames** and operate effectively under diverse lighting and environmental conditions. The collected video serves as the raw input for both model training and real-time inference.

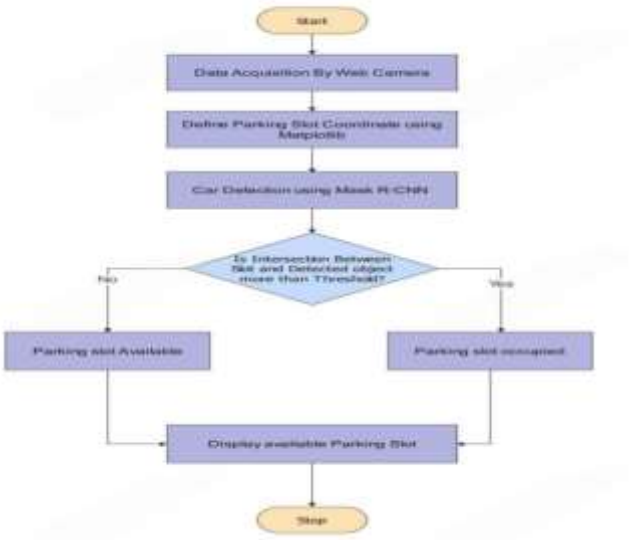

Fig 3.1 System Architecture of Parking Slot Vacancy Detection System

3.2 Data Preprocessing

Once the video data is collected, it undergoes a preprocessing stage to extract meaningful frames for analysis. The preprocessing includes:

- **Conversion** of video streams into standardized image formats
- **Resizing** of frames to ensure uniformity
- **Contrast normalization** to enhance visual clarity
- **Noise reduction** to remove irrelevant background data

This step ensures clean and structured input for the object detection model, improving detection accuracy and inference speed.

3.3 Defining Parking Slot

A critical component of the system is the manual annotation of parking slots. Using a graphical user interface, the user defines the boundaries of each slot. These coordinates are stored in a .p (pickle) file. During inference, these defined slot regions are used to analyze the **overlap** between detected vehicles and parking spaces. Accurate definition of these regions is vital for correct occupancy detection.

3.4 Model Implementation

The object detection process relies on the **Mask R-CNN** deep learning model, enhanced with a **ResNet backbone** for feature extraction. Mask R-CNN is capable of:

- Detecting vehicles in each frame
- Segmenting each object instance
- Outputting bounding boxes, masks, and class labels

Using **Intersection over Union (IoU)**, the system compares detected vehicle regions with predefined parking slot areas to determine whether each slot is **occupied** or **vacant**.

3.5 System Integration And Real-Time Processing

The entire system is deployed as a **full-stack web application**:

- The **backend** (built using Flask or a similar Python framework) handles video processing and model inference.
- The **frontend UI** displays live video, colored slot overlays, and booking options.

The architecture supports **edge computing** for faster response times and can be extended to use **cloud-based storage and computation** for large-scale implementations. This integration ensures that users receive real-time updates on parking slot availability with minimal latency.

3.6 Result Display And Visualization

The results are presented through a **dynamic dashboard** that provides:

- **Live video feed** with real-time overlays
  - **Green** for vacant slots
  - **Red** for occupied slots
  - **Yellow** for booked slots
- Slot booking/unbooking functionality
- **Analytics tools** to track occupancy trends, generate heatmaps, and display slot usage statistics
- **User notifications** for changes in slot status
- Integration with **navigation apps** to direct users to the nearest available parking space

This interface is designed to be user-friendly and accessible from multiple devices, including desktops, tablets, and smartphones.

Fig 3.2: Home Page

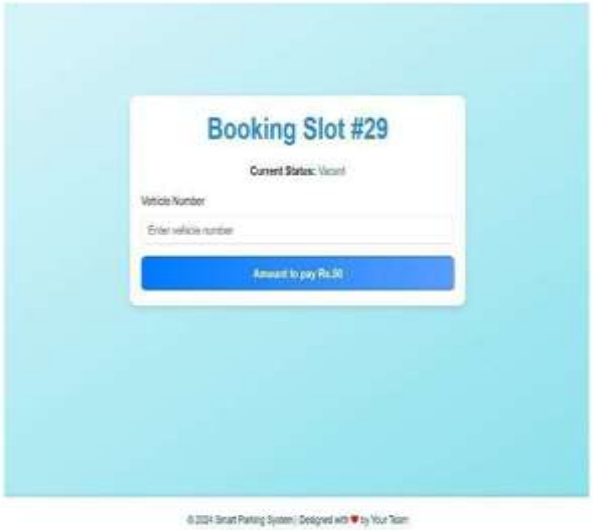

Fig 3.3: Booking Slot

Fig 3.4 : Parking Payment Interface

CONCLUSION

The Parking Slot Vacancy Detection system developed in this study presents a practical and innovative approach to resolving urban parking challenges. By leveraging advanced machine learning techniques, specifically the **Mask R-CNN model**, the system can accurately identify and classify vacant and occupied parkingslots in real time. This capability not only reduces the time drivers spend searching for parking but also contributes to **lower traffic congestion**, **decreased fuel consumption**, and **improved environmental conditions**.

The modular and scalable architecture ensures adaptability across various environments—from open parking lots to multi-level parking structures. With the integration of **cloud services**, **GPU acceleration**, and **real-time visualization tools**, the system meets the requirements for modern smart city infrastructure.

Challenges such as low-light performance and environmental variability have been addressed through high-quality cameras and robust preprocessing techniques. The user-friendly interface allows for live status monitoring, slot booking, and occupancy trend analysis, making it equally useful for drivers and parking managers.

In summary, this system bridges the gap between traditional parking methods and modern intelligent systems, offering a reliable, real-time solution that can evolve with emerging urban mobility needs

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