

國立臺灣科技大學資訊工程系

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總報告

Real-Time Roadside Parking Space Detection using Machine Learning

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Abstract

The rising number of cars globally has significantly increased the demand for parking, making it challenging and time-consuming, thereby worsening traffic congestion. This project aims to develop a real-time roadside parking detection system using edge computing and object detection technologies to help drivers find the nearest parking space. The system provides real-time notifications and shortest path recommendations to reduce parking time and costs, improve traffic flow, and enhance space utilization.

The system employs YOLOv7 for object detection, trained with roadside scene data to identify parking spaces quickly. Edge computing reduces latency by processing data locally, minimizing transmission, reducing server load, and enhancing privacy.

Navigation features provide optimal routes based on traffic conditions, dynamically updating driving routes and parking availability. Visual prompts assist drivers in parking efficiently.

The system reduces parking search time and urban traffic pressure while promoting green city development by reducing emissions. Future features include parking reservations, usage prediction, smart city integration, and payment options for added convenience.

Our goal is to create an intelligent parking ecosystem integrated with other smart city infrastructure to enhance urban traffic management, offering a convenient and eco-friendly solution as cities evolve. Source code is released in [GitHub](#).

Key word: Edge computing, Real-time roadside parking detection, Object detection, YOLOv7, Navigation system, Optimal route recommendation, Web service

Introduction

With urbanization and the continuous increase in the number of vehicles, finding an available parking space has become a significant challenge for drivers, particularly in densely populated areas like Taipei, where the average time spent searching for parking is 13.7 minutes. This not only leads to wasted time and fuel but also contributes to traffic congestion and environmental pollution. In addition, the frustration and stress experienced by drivers further impact their overall quality of life, creating a pressing need for more effective parking solutions. To address these issues, this project proposes a real-time roadside parking system that helps drivers quickly and efficiently locate the nearest vacant roadside parking spaces.

The system leverages state-of-the-art object detection technology to detect and display available parking spots in real time. By integrating these technologies with a user-friendly website, drivers can receive shortest path recommendations, providing a smoother parking experience. The combination of real-time data and advanced navigation ensures that drivers spend minimal time searching for parking, thereby making more efficient use of urban infrastructure.

The objectives of this project are to reduce the time and cost of finding parking spaces, increase the utilization rate of parking spots, and improve the overall user experience for drivers. This approach not only benefits individual drivers but also has a positive impact on the community as a whole, contributing to cleaner air and reduced congestion. The proposed system is scalable, allowing for easy adaptation to different urban environments, suitable for both large and small cities.

To achieve these goals, the system uses advanced image processing techniques employing YOLOv7 to identify available parking spaces. These models are trained on extensive datasets of roadside scenes, ensuring the robustness and reliability of the system. In addition, edge computing is incorporated to process data locally, minimizing the need to transmit information to a central server and thus reducing latency. Localized data processing enhances the system's responsiveness, providing real-time feedback to drivers and ensuring that parking information remains current.

The system also integrates navigation features that provide drivers with optimal route recommendations based on current traffic conditions. By combining map APIs and real-time traffic flow data, the system can dynamically update driving routes, helping drivers quickly reach available parking spaces. Meanwhile, the system continually updates parking availability information to ensure that drivers receive the most accurate and up-to-date data. When drivers approach the parking space, the system provides visual and audio navigation prompts, guiding them to park more easily and efficiently. This integrated approach reduces the stress associated with parking and enhances overall driver satisfaction.

The project also has the potential to evolve into a comprehensive smart parking ecosystem. In the future, we plan to add more advanced features, such as parking reservations, allowing drivers to reserve a parking spot in advance, ensuring availability upon arrival. In the future, we hope to expand the scope of services, integrating payment gateways to allow drivers to pay for parking directly through the system, further simplifying the parking experience. Predictive analytics could also be used to anticipate parking demand based on historical data, providing proactive recommendations to drivers and optimizing parking space utilization. By integrating these features, the system aims to provide a seamless parking experience from start to finish.

We believe that with the development of smart cities, such a parking management system will become an essential part of future urban life, offering people a more convenient and

environmentally friendly travel experience. By leveraging advanced technologies such as edge computing, deep learning, and real-time data analytics, this project lays the foundation for smarter urban living. Ultimately, our goal is to revolutionize how drivers find parking spaces, reduce the environmental impact of vehicle emissions, and contribute to the creation of smarter, more sustainable urban environments. Through this research, we explore the potential of edge computing and object recognition in transforming urban mobility, creating cities that are not only more efficient but also more livable.

Structure

The system architecture consists of four layers, forming a complete workflow from user interaction to edge computing. First, users can access the system via mobile phones or computers to check real-time parking space availability or locate the nearest available roadside parking spots. The front-end layer processes user requests and returns parking space status information, enhancing the user experience through an intuitive interface.

In the back-end layer, the system includes two databases: a user database that manages personal information and usage records, and a parking status database that records the real-time occupancy of parking spaces. These data are dynamically updated based on the computation results from edge devices. The model is deployed on edge devices, leveraging YOLOv7 to capture vehicle information in real-time, detect occupied spaces, and calculate the number of available parking spots. The data processing capability at this layer reduces the load on the central server while accelerating system response times.

The core feature of this architecture lies in leveraging edge computing for efficient data processing, combined with object detection technology for accurate parking space detection and classification.

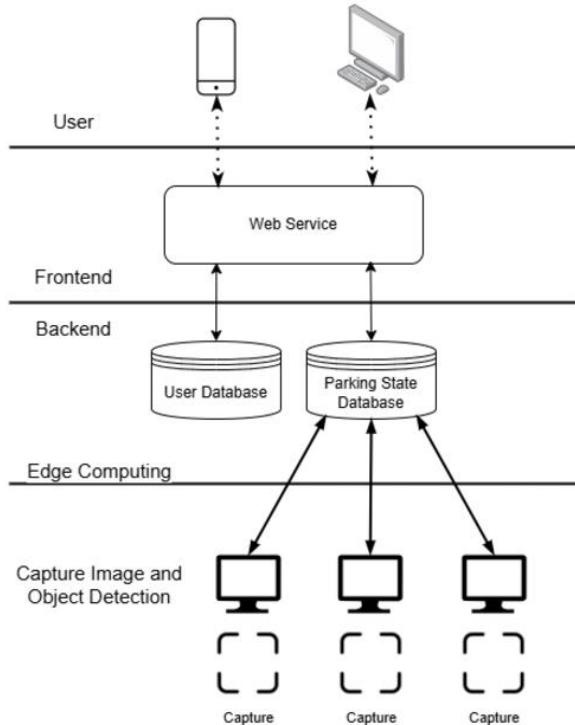


Fig. 1. This is our roadside parking management system architecture based on edge computing and object detection technology encompasses the entire process design, including user interaction, data processing, and real-time parking space status updates. This system enhances parking lot management efficiency and improves the user experience.

Result

1. Object Detection Models :

- **Model Training :**

The object recognition part of this study is based on the YOLOv7 model, with the primary goal of achieving efficient object detection and classification through deep learning. The training process includes calculations for bounding box, classification, and distribution focal loss, and evaluates the model's precision, recall, and mean average precision (mAP).

During the training process, the bounding box loss, classification loss, and distribution focal loss all showed a steady decline as the number of training iterations increased, indicating a gradual improvement in the model's performance in object localization and category differentiation. In terms of performance metrics, the model's precision ultimately increased to 97.0%, recall reached 94.0%, and mAP50 stabilized at 97.6%, demonstrating excellent overall detection performance. The validation loss tended to stabilize in the later stages of training, indicating that the model has good generalization capability.

Through 300 rounds training, in the final metrics, the model's mean average precision (mAP50) is 97.6%, precision is 97.0%, and recall is 94.0%. These high-level metrics indicate that the model has strong overall capabilities in object localization and classification, making it

suitable for deployment in practical applications.

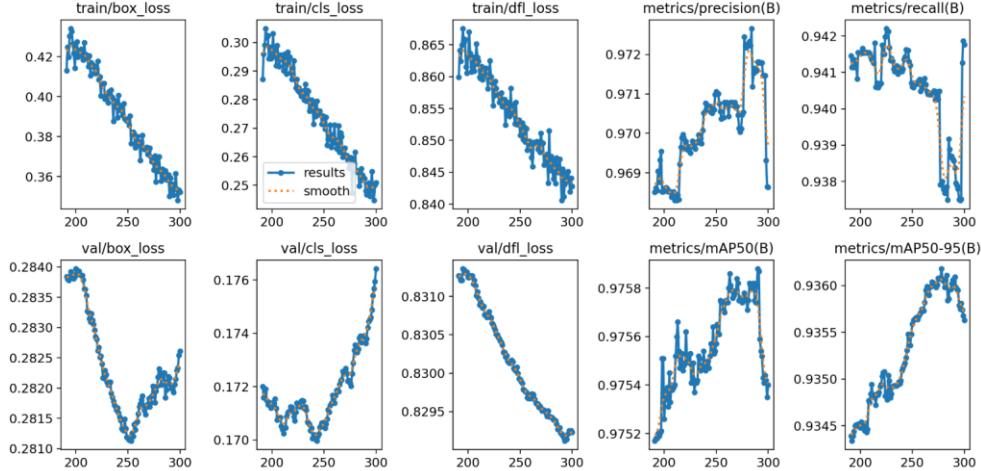


Fig. 2. Illustrates the training and validation process of the model, focusing on the loss and performance metrics over the course of training epochs. The first row presents the training metrics, including box loss, classification loss, and objectness loss, as well as precision and recall metrics. These curves demonstrate a steady decrease in loss values and improvement in precision and recall as training progresses, indicating the model's convergence and increasing accuracy. The second row highlights the validation metrics, showing the box loss, classification loss, and objectness loss, alongside mean Average Precision (mAP) metrics at thresholds 0.5 and 0.5:0.95. The validation losses exhibit consistent downward trends, while mAP values improve, confirming the model's ability to generalize to unseen data.

● Model Testing :

We conducted tests on the trained model to evaluate its ability to identify roadside parking spaces and occupancy status in real-world environments. The testing data used surveillance camera footage as input to verify whether the model could accurately detect both occupied and empty parking spots.

As shown in **Fig.3**, the model successfully identified three parking spaces, correctly marking two of them as occupied (labeled as "occupied") and three as available (labeled as "parking spot"). These results demonstrate that the model has good accuracy and practicality in parking space detection and classification, highlighting its potential for smart parking lot management.

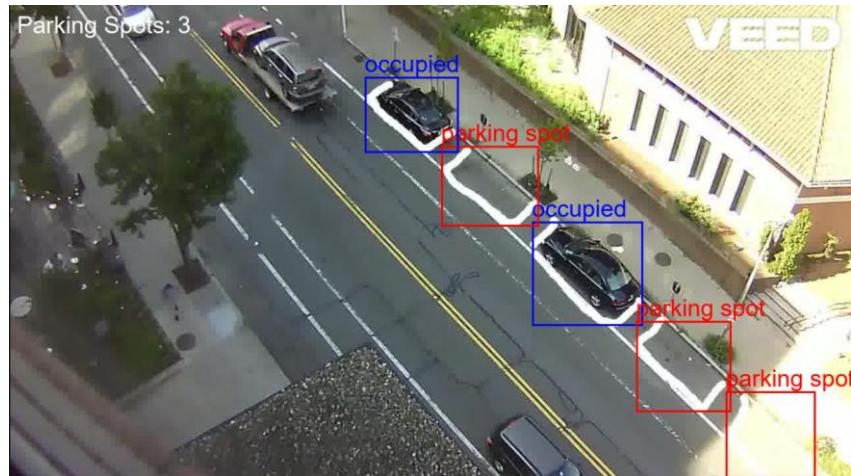


Fig. 3. The result of the model's parking space detection in a real road scenario, showing both occupied and parking spots to validate its feasibility for smart parking lot management.

2. Overall Results - Web Service and Operation Process

In our project, we have set the number of service roads to two. At the start of the operation, app.py needs to be executed, which generates a URL for users to access the service we provide. Then, detection1.py and detection2.py are executed. These files are the core programs for object recognition, responsible for detecting objects in the images and returning the results.

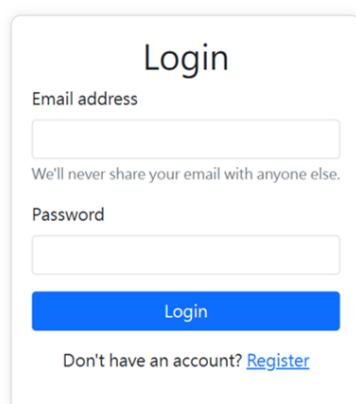
Meanwhile, edge devices will execute take_photo.py to capture images of the road sections. These images are sent to detection1.py and detection2.py for object detection. The results of the object detection are then sent back to the Parking Space Database to serve as a basis for subsequent operations.

When users visit the webpage through the generated URL, they are required to log in with their personal information (Fig. 4(a)). If they are new users, they need to register an account and password to officially use the services provided by the webpage (Fig. 4(b)). After logging in, users can access the main page of the roadside parking system, where the system will request the user's current location information (Fig. 6). After obtaining the user's location, the webpage will display an introduction to the system's features (Fig. 5).

Based on this, users can utilize the map service to view the images captured by the edge devices and, through the object detection results, understand the current number of empty spaces in the specified road sections (Fig. 7).

To ensure the parking status is updated quickly, we have designed a feature that automatically refreshes the roadside parking status every minute. This allows users to quickly obtain the latest parking space information via the webpage without needing to be on-site, thereby maximizing time efficiency and minimizing spatial management costs.

At the bottom of the webpage, we provide a FAQs section to address common questions and concerns users may have (Fig. 8).



Login

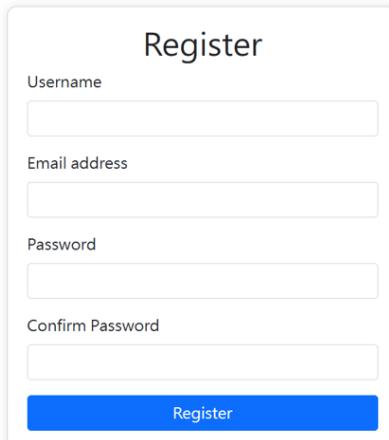
Email address

We'll never share your email with anyone else.

Password

Login

Don't have an account? [Register](#)



Register

Username

Email address

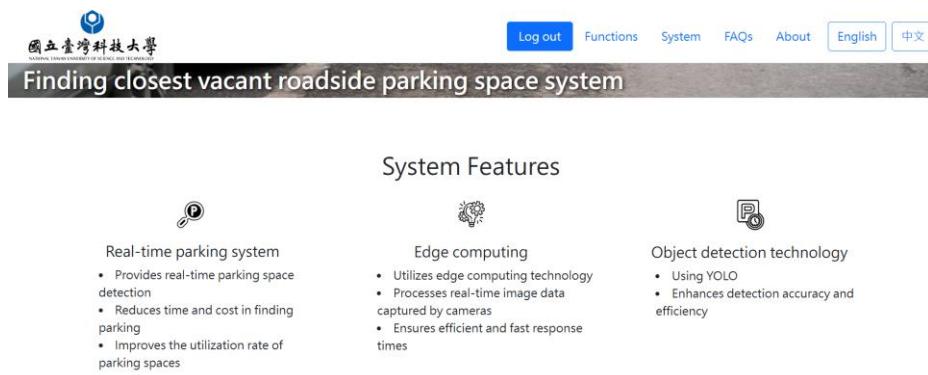
Password

Confirm Password

Register

(a) (b)

Fig. 4.(a) Login Page: This page requires users to input their email address and password. If they do not have an account, they can click "Register" to create one. (b) Register Page: New users must provide a username, email address, and password to complete the registration process.



The screenshot shows the system's homepage with the title "Finding closest vacant roadside parking space system". It features a navigation bar with "Log out", "Functions", "System", "FAQs", "About", "English", and "中文". Below the title, there's a section titled "System Features" with three columns:

- Real-time parking system**: Provides real-time parking space detection, reduces time and cost in finding parking, and improves the utilization rate of parking spaces.
- Edge computing**: Utilizes edge computing technology to process real-time image data captured by cameras, ensuring efficient and fast response times.
- Object detection technology**: Uses YOLO to enhance detection accuracy and efficiency.

Fig. 5. System Features Overview: This page highlights the key features of the system, including real-time parking detection, edge computing, and object detection.

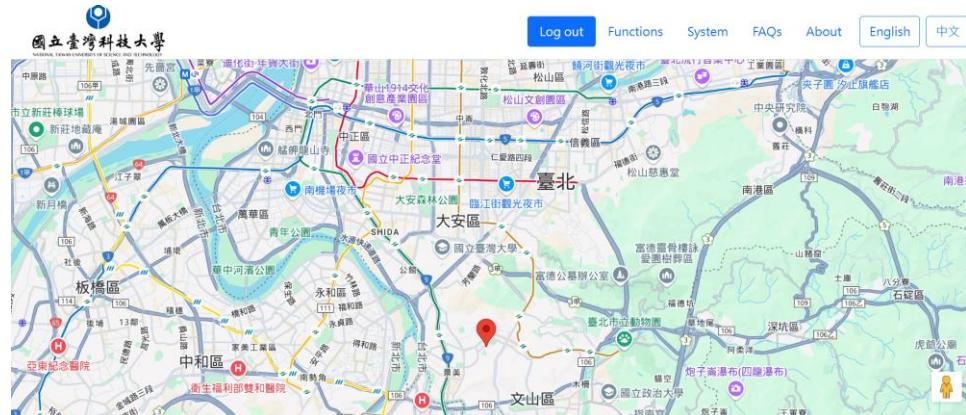


Fig. 6. Map Service Page: Displays the user's current location and real-time images captured by edge device indicating the number of available parking spaces.

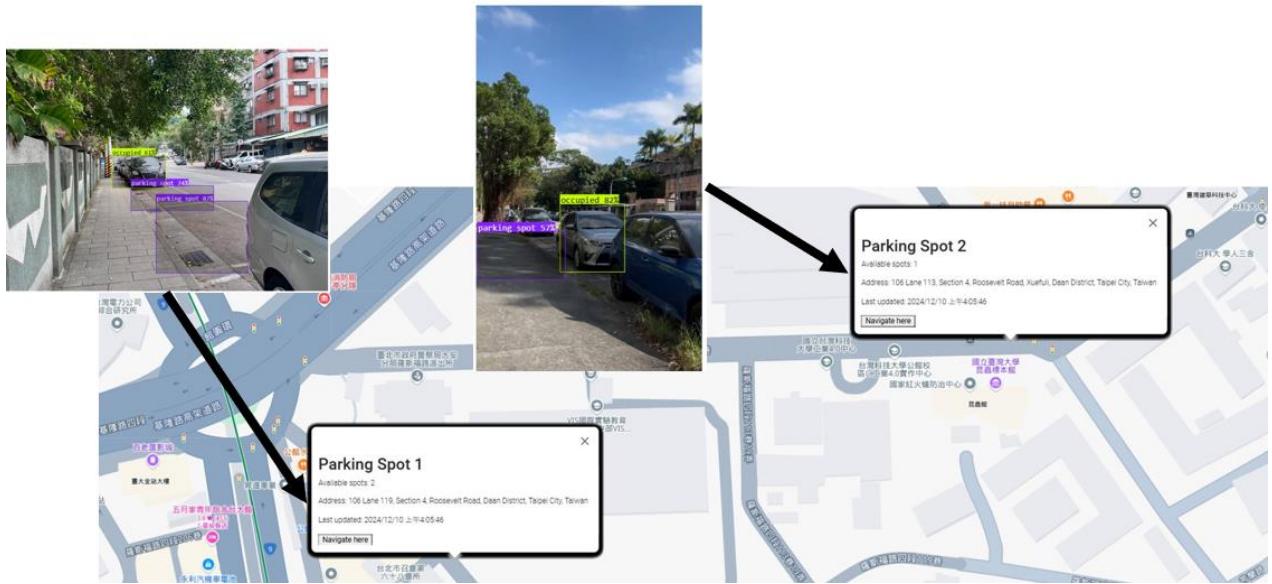


Fig. 7. In this picture, the user can successfully see that there are two parking spots in parking spot 1, and one parking spot in parking spots 2. If the user would like to go to one of these two spots, they can push “Navigate here” button, and then directed to the spot.

FAQs

What is the accuracy of the parking spot detection?	
Can I reserve a parking spot in advance?	
How often is the parking information updated?	

Fig. 8. Frequently Asked Questions (FAQs): Provides answers to common questions, such as detection accuracy and system update frequency.

Future Work

1. Expansion of System Functionality and Multi-Site Deployment

In the future, the system will be expanded to multiple locations to achieve multi-site synchronized parking monitoring and analysis, and to improve the real-time performance of image transmission and display. This will ensure that drivers can always be informed of the parking situation at different locations, enjoying convenient parking services wherever they are. Additionally, navigation features will be added to help drivers quickly find available parking spaces, reducing the time and effort needed to search for parking and improving overall travel

efficiency. Future expansions will also consider the characteristics of different areas to meet specific local needs.

2. Optimization of Object Recognition Model

The object recognition model will be continuously optimized to improve recognition accuracy and performance, adapting to different lighting and weather conditions to ensure stable recognition in various environments. To further enhance recognition capabilities, future improvements will incorporate parking data for prediction, learning parking patterns, and providing intelligent parking suggestions to help drivers find parking spaces during high-demand periods. The optimization of this model will include recognizing more types of vehicles and adapting to different parking environments to handle increasingly complex parking scenarios.

3. Development of Reservation Services

In the future, a parking reservation feature will be added, allowing users to select and reserve parking spaces in advance, avoiding situations where no parking is available upon arrival, especially during peak times or specific events. At the same time, integrating real-time monitoring systems will ensure the accuracy and convenience of reservation services, providing real-time updates on parking availability so users can always be aware of the status of their reservations. Additionally, automatic cancellation and reminder functions may be considered to enhance user experience and ensure the efficient operation of reservation services.

4. Integration with Smart City and Commercial Applications

The system will be integrated with smart city infrastructure such as smart streetlights or surveillance systems, and commercial applications will be explored, such as collaborating with parking management companies or even introducing shared parking concepts to expand commercialization opportunities. This integration will help improve the overall intelligence level of the city, further reduce parking management costs, and provide more efficient services. Furthermore, the system could be integrated with other smart city services, such as traffic management and environmental monitoring, forming a more comprehensive urban infrastructure network. Future commercial applications may also include partnerships with businesses to offer parking discounts or promotions, attracting more users and creating additional commercial value.

Related Work

<https://arxiv.org/abs/2207.02696>

<https://ieeexplore.ieee.org/abstract/document/6815565>

<https://ieeexplore.ieee.org/abstract/document/10150637>

<https://ieeexplore.ieee.org/abstract/document/10047820>

<https://ieeexplore.ieee.org/abstract/document/8221062>

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<https://ieeexplore.ieee.org/abstract/document/8782760>

<https://ieeexplore.ieee.org/abstract/document/9852546>

<https://ieeexplore.ieee.org/abstract/document/10174475>