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Intelligent Parking Space Detection Using Yolov11 with an Enhanced Backbone Network for Accurate Real-Time Vehicle Monitoring

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ABSTRACT: The difficulties of parking management have been aggravated by rapid urbanization and growing number of vehicles, leading to traffic congestion, wastage of fuel and environmental pollution. To address such issues, this paper proposes a Deep Learning (DL) based Parking Space Detection (PSD) framework for accurately detecting free and occupied parking spaces. First, parking lot images are enhanced by using Contrast Limited Adaptive Histogram Equalization (CLAHE). Then, Region of Interest (ROI) is extracted to focus on relevant parking areas. Then, the processed images are classified by a YOLOv11 model with an enhanced backbone network, the EfficientNet-B7, for feature extraction and detection accuracy improvement. The proposed framework integrates the CLAHE, ROI segmentation, and the EfficientNet-B7 enhanced YOLOv11 model for accurate PSD. Experimental results show that the proposed framework achieves 94% mAP50, 91% precision and F1-score of 89%, which are higher than conventional DT, RF, YOLOv5, and Faster R-CNN methods. The proposed system provides reliable real-time monitoring of parking occupancy and enables efficient, intelligent and sustainable smart parking management.

Keywords: CLAHE, ROI, YOLOv11, EfficientNet-B7, DL

1. Introduction

Due to rapid urbanization, the number of cars has significantly increased, resulting in traffic congestion and inadequate parking spaces, which is one of the main problems faced by cities today [1]. Optimal management and allocation of parking space are crucial for reducing congestion, increasing mobility, and improving the quality of city life [2-3].

The parking problems do not end with shortage of parking places; drivers looking for parking places lead to increased fuel usage, pollutants emission, and traffic congestion, while illegal parking causes traffic disruption [4-5]. Furthermore, seasonal conditions, fluctuating parking needs, and the use of electric cars requiring charging stations make the parking task more complicated [6]. Hence, the need for intelligent parking systems to improve the effectiveness of parking and sustainability of the urban transport. To solve these problems, the developed architecture uses pre-processing, segmentation, and classification approaches [7-8].

Conventional classification models have been extensively used for PSD in the context of ML owing to their simplicity and efficiency in solving image classification problems. The commonest algorithms used include SVM, DT and RF. In SVM, classification of parking spaces is done using the optimal hyper plane based on manually extracted image features; hence, it gives good performance in small data sets. In DT, classification of parking occupancy involves iterative application of decision rules on the manually extracted features, and its major advantage is that it is fast and easily understood. The main advantage of RF, however, is increased reliability in classification through the combination of multiple decision trees using the majority rule, thus avoiding over fitting. While all these techniques yield acceptable performance in controlled environments, their major weakness is that they use handcrafted feature extraction methods, do not have the ability to learn complex patterns in images, and cannot be used for end-to-end real-time object detection [9-11]. For these reasons, the proposed framework uses YOLOv11 classification model, which performs end-to-end object detection, has higher detection accuracy, faster real-time inference, precise localization of occupied and vacant parking spaces, and is improved with an EfficientNet-B7 backbone.

1.1 Research gap

Existing parking space detection methods achieve satisfactory performance, but they are typically based on hand-crafted features or computationally intensive models, leading to limited real-time applicability and detection accuracy under various lighting and environmental conditions. To address these issues, this work proposes a YOLOv11 framework with an EfficientNet-B7 enhanced backbone, combined with CLAHE and ROI segmentation, to ensure accurate and efficient real-time parking space detection

2. Recent Works

Sayeed *et al* (2023) [12] have proposed used the Weighted K-Nearest Neighbors (WKNN) algorithm for parking space classification. The method enhances the accuracy of classification and allows the real-time parking monitoring. However, the method is based on the handcrafted features and complex parking environment. **Satyanath *et al* (2023) [13]** have developed a smart parking detection system using CNN for detection of occupied and vacant parking space in hazy conditions. The method enhances detection accuracy, but requires large training datasets and has a high computational complexity that restricts its real-time performance. **Muhammad *et al* (2022) [14]** have introduced a ResNet50 based parking space detection system that classifies occupied and vacant parking spaces by employing deep feature extraction. The method increases classification accuracy but requires more computational resources and training time. Wei **Jun *et al* (2023) [15]** have proposed a deep learning and support vector regression (SVR) based approach for open parking space prediction. The method improves the prediction accuracy but requires a large training data and high computational resources.

2.1 Objectives

- To develop a YOLOv11 DL based PSD framework to accurately identify empty and filled parking spots.
- To improve parking images by CLAHE for improved visual quality.
- To extract parking regions through ROI based segmentation
- To identify real time parking occupied detection, classifying the parking spaces using YOLOv11 model correctly.
- To improve PSD classification using YOLOv11 model with an EfficientNet-B7 enhanced backbone
- To offer reliable real-time smart parking systems.

3. Proposed Work Explanation

Figure 1 represents that the proposed framework for detecting parking spaces consists of the following key steps pre-processing, segmentation, classification, enhanced feature extraction, and prediction. The parking space input images are first obtained from the dataset. The pre-processing stage includes CLAHE to enhance the image contrast and make the parking regions more visible under different illumination conditions. In the segmentation phase, the next step is to do the ROI extraction so as to extract the required parking areas and remove unnecessary background information. The segmented ROI is then fed to the YOLOv11 classification model to detect occupied and vacant parking spaces.

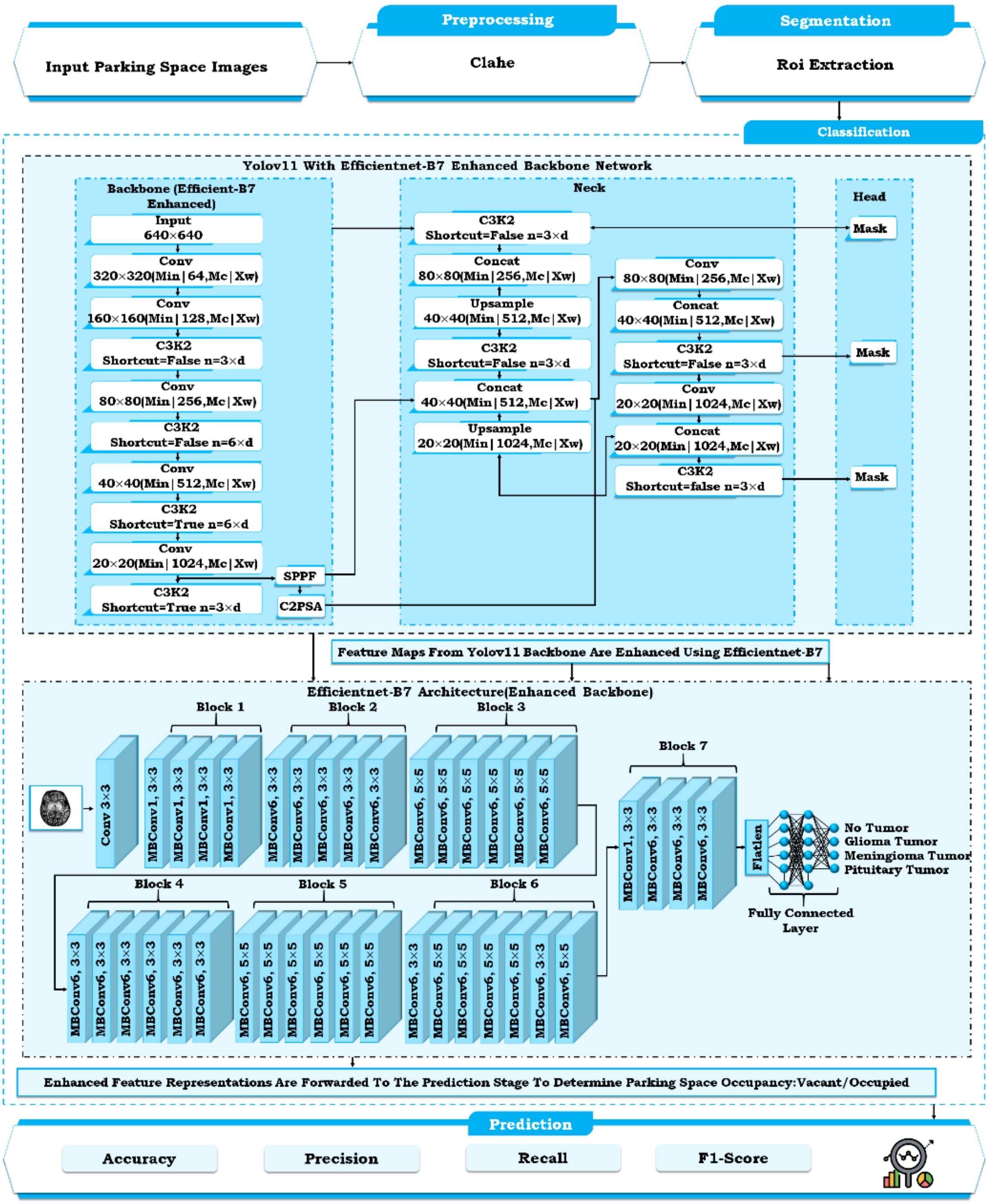

Figure 1: *Proposed System Architecture*

The extracted features are further optimized by an EfficientNet-B7 enhanced backbone network to improve the feature representation and detections accuracy. Finally, the prediction phase accurately classifies the parking status of each parking space as either occupied or vacant, enabling efficient smart parking management

4. Proposed system modelling

4.1 CLAHE

CLAHE is used to enhance the contrast of images of parking space captured under different lighting conditions. It improves the visibility of parking areas using histogram equalization on small image blocks and controlling noise amplification. The clip limit parameter is defined by

$$\beta = \frac{MN}{G}\left\{1 + \frac{\alpha}{100}\left(AS_{max} - 1\right)\right\} \qquad (1)$$

Where M and N are the pixels in each region, G is the grayscale level, α is the clip factor and AS max is the maximum allowable slope. Then, the augmented images are fed into the ROI segmentation stage to extract parking spaces accurately.

4.2 ROI Segmentation

The extraction of the ROI is done to extract important parking zones from the enhanced images by getting rid of unwanted background data. The ROI is made up of only the parking spots and vehicles. This makes the data less complex and more accurate. The images extracted after segmentation have information that is useful in detecting the occupied parking spots. The ROI image is then fed into YOLOv11 algorithm to classify the parking spaces. The proposed framework combines YOLOv11 with an EfficientNet-B7 enhanced backbone for accurate and real-time parking spaces classification.

4.3 YOLOv11 based EfficientNet-B7

The proposed framework uses YOLOv11 for end-to-end object detection to classify parking spaces as occupied. The design consists of three major components backbone, neck and head. The C3k2, SPPF and C2PSA modules of the Backbone extract multi-scale features from the segmented parking images, which represent features efficiently. The Neck stitches and refines these features and the Head predicts the parking occupancy status by generating bounding boxes, object confidence scores, and class probabilities.

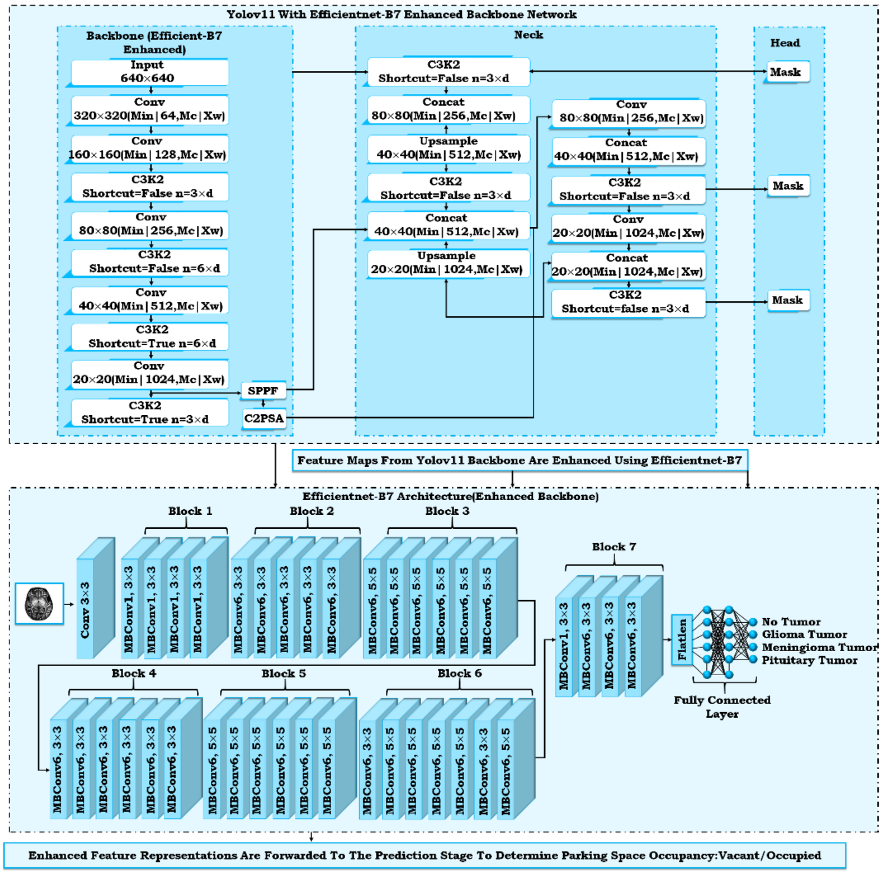

Figure 2: *Architecture of YOLOv11 based EfficientNet-B7*

The feature extraction represented as

$$F = B(I) \qquad (2)$$

Where *I* is input ROI image and *F* is the extracted feature map generated by backbone network for accurate parking space detection and classification.

The object confidence is determined according to

$$C = P(\text{Object}) \times \text{IoU} \quad (3)$$

Where $P(Object)$ corresponds to probability of object existence, and IoU quantifies the overlap between predicted bounding box and its ground truth counterpart.

The probability of the last classification is calculated using the Softmax function:

$$P_i = \frac{e^{zi}}{\sum_{j=1}^{N} e^{zj}} \quad (4)$$

In this equation, z_i indicates prediction score of class i and N denotes overall number of parking occupancy classes. An EfficientNet-B7 enhanced backbone network is incorporated with the YOLOv11 architecture to further improve the discriminative ability of these extracted feature maps and boost the overall parking occupancy classification accuracy.

EfficientNet-B7 uses a compound scaling method that uniformly scales width and input image determination for efficient feature learning with lower computational complexity.

The compound scaling is provided by

$$d = \alpha^{\phi} \quad (5)$$

$$w = \beta^{\phi} \quad (6)$$

$$r = \gamma^{\phi} \quad (7)$$

Where $d, w\ and\ r$ are the network depth, width and input image resolution respectively α, β and γ are scaling constants ϕ is the compound scaling coefficient.

After global average pooling, the extracted feature vector is

$$Z_{\text{EfficientNet}} = \text{Softmax}(Wf + b) \quad (8)$$

Where f is the global feature vector, b is the bias vector of the fully connected layer. MBConv blocks, depthwise separable convolutions and SE modules are employed in EfficientNet-B7 for boosting feature extraction. The enhanced feature maps are then passed on to the prediction stage for accurate real-time parking occupancy detection.

5. Results and Discussion

The proposed model is evaluated on Parking Lot Computer Vision Dataset. The results prove accurate classification of PSD, and the method is superior to existing methods for real-time vehicle monitoring.

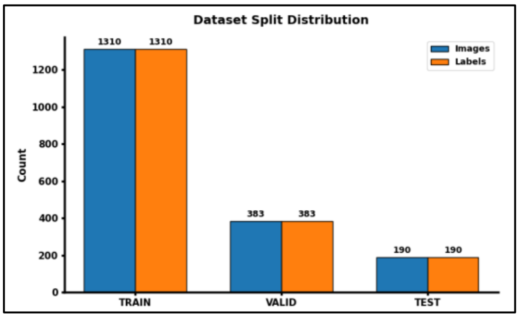

Figure 3: *Dataset Split Distribution*

Figure 3. shows distribution of training, validation and test datasets. It consists of 1310 training, 383 validation and 190 testing samples with an equal number of images and labels. The dataset is divided into a training, a validation and a testing set. Model learning was performed on the training set, hyper parameter tuning is performed on the validation set, and the performance of the final model on unseen parking images was evaluated on the testing set.

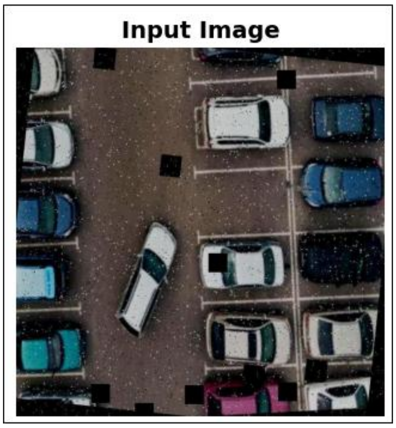

Figure 4: *Input image used for PSD*

Figure 4. shows the original image of the parking lot that is used as the input for the proposed model.

This is the initial image before the detecting the parking spaces and reprocessing.

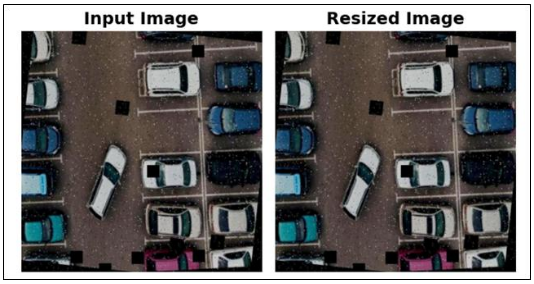

Figure 5: *Input and resized images*

Figure 5. shows the comparison between original input image and resized image. Resizing is used to ensure that the image sizes are suitable for efficient processing by the detection model.

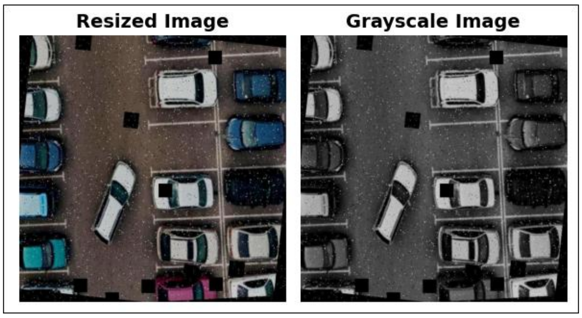

Figure 6: *Conversion of Resized image into grayscale for preprocessing*

Figure 6. represents that the image is resized and converted to gray scale as shown in the figure. Grayscale reprocessing reduces the complexity of the image, and thus makes the detection process easier.

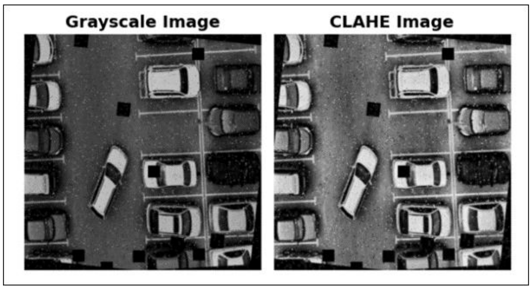

Figure 7: *Grayscale and CLAHE enhanced images*

Figure 7. shows the Comparison of grayscale image with CLAHE enhanced image. The image contrast is improved by CLAHE, which makes the parking spaces and the vehicle features more distinguishable.

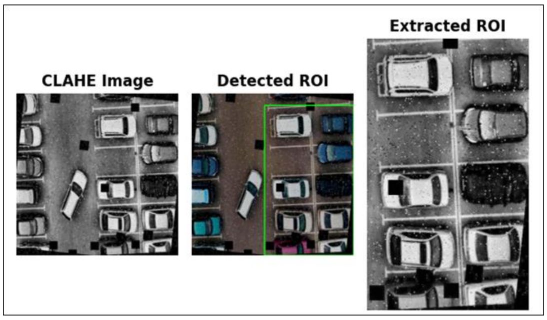

Figure 8: *ROI detection and extraction process*

Figure 8. shows the detection and extraction of ROI from the CLAHE enhanced image. The extracted ROI is concentrated on the parking lot for accurate analysis of vehicles and parking spaces.

Table 1: *Assessment metrics of proposed classification model*

Evaluation metrics	
mAP50	94%
Precision	91%
F1 score	89%

Table 1. shows that the model achieved a mAP50 of 94%, precision of 91% and F1-score of 89% which indicates that it classifies effectively and reliably.

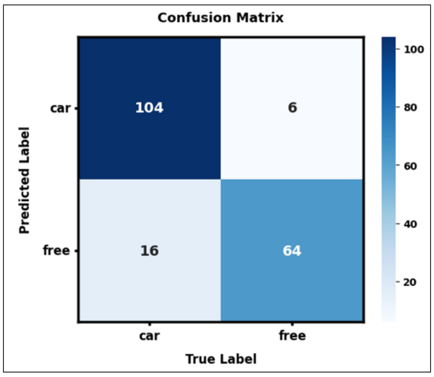

Figure 9: *Confusion matrix illustrating parking space classification*

Figure 9. represents the confusion matrix for classification of car and free parking spaces. It shows the high classification accuracy with the

most of the samples are correctly classified and only a few misclassification.

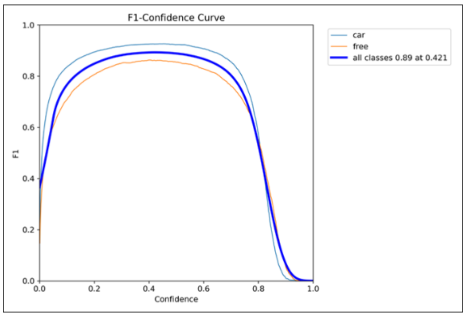

Figure 10: *F1 confidence curve threshold for parking space classification*

Figure10. shows the relationship between the F1-score and the confidence threshold for the car and free classes. The maximum overall F1-score of the model is 0.89 at the confidence threshold of 0.421.

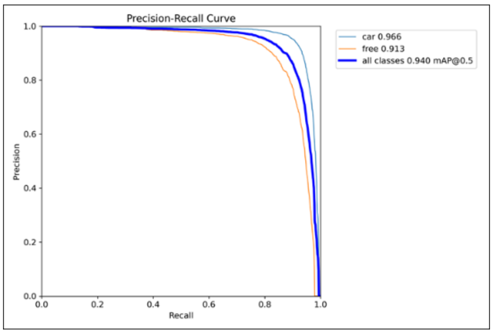

Figure 11: *Precision and recall curve*

Figure 11. represents the Precision-recall performance for car and free classes. The proposed model achieves a high detection accuracy with an overall mAP@0.5 of 0.940.

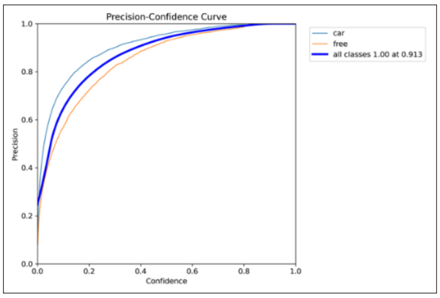

Figure 12: *Precision confidence curve*

Figure 12. shows Variation of precision with different confidence thresholds for the vehicle and free classes. The model reaches a maximum overall precision of 1.00 at a confidence threshold of 0.913.

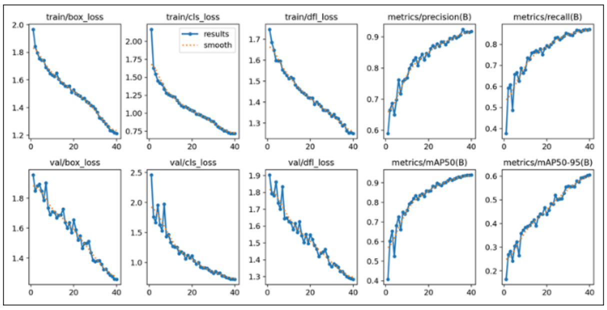

Figure 13: *Training and validation performance*

Figure13.represents that the results show a trend of decreasing loss and improving detection performance, which indicates the model is converging successfully.

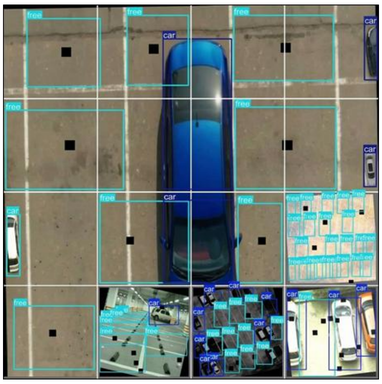

Figure 14: *Parking space detection and classification results*

Figure 14. shows that the Output of the proposed model in which parking spaces are classified as vehicles or free. The work precisely locate and label the detected parking slots, which demonstrates the effectiveness of parking occupancy detection.

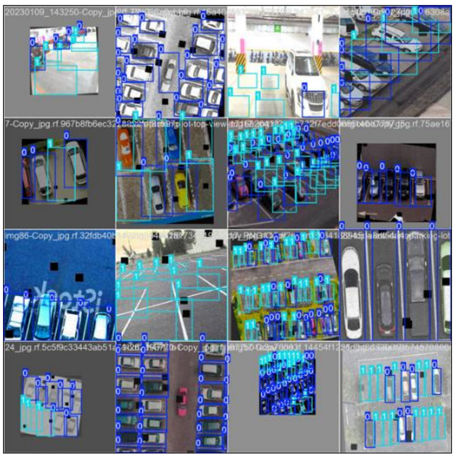

Figure 15: *Sample detection results on parking dataset*

Figure15. shows the sample detection results on different parking lot images. The proposed model accurately detect and classify the parking spaces as occupied or free in different situations.

Table 2: *Comparison of F1 score performance of different methods*

F1 score	
Method	Value
DT [10]	77%
RF[11]	83%
Proposed	89%

Table 2. presents the F1-score of DT, RF, and the proposed model. The proposed approach obtains the best F1-score of 89% showing a better precision-recall trade-off compared to the state-of-the-art methods.

Table 3: *Comparison of mAP50 performance*

mAP50	
Method	Value
YOLOv5 [16]	93%
Faster RCNN [17]	89%
Proposed	94%

Table 3. shows the mean Average Precision (mAP) obtained by YOLOv5, Faster R-CNN and the proposed model for PSD. The proposed approach achieves the highest mAP of 94% which shows better detection accuracy than the existing methods.

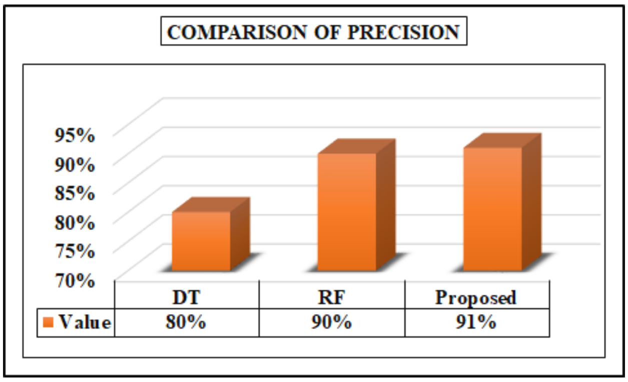

Figure 16: *comparative analysis of precision between existing and proposed model*

Figure.16.shows that the proposed method achieves the highest precision of 91% which shows that it predict with more reliability than the existing approaches

6. Conclusion

This paper proposed a YOLOv11 model with Enhanced Backbone Network for accurate real-time vehicle monitoring. The framework proposed uses image pre-processing and an improved YOLOv11 architecture to better detect and classify parking spaces. Experimental results obtained 94% mAP50 91% precision, and F1-score of 89% which outperformed DT, RF, YOLOv5 and faster R-CNN methods. The results demonstrate the accuracy, reliability and suitability of the proposed framework for smart parking management, intelligent transportation systems and real-time parking occupancy monitoring. Future work includes larger parking datasets, edge-device optimization, and multi-camera smart parking systems.

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