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EXPLORING THE USE OF WEB APPLICATIONS AND NEURAL NETWORKS FOR CAR PARKING SERVICES

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Abstract

Intelligent parking systems that capitalize on the characteristics of deep-learning architectures have become an important point of research due to their ability to improve efficiency, reduce traffic congestion and improve the experience of drivers. The availability and ineffective management of parking spaces is a major problem in most cities, leading to traffic congestion and pollution. This study aims to introduce a state-of-the-art implementation of intelligent parking systems using neural networks and web application development. The optimization of neural networks enables careful analysis of images and videos from surveillance cameras to quickly identify available parking spaces in real time. These implementations offer innovative solutions for drivers looking for parking spaces, thus reducing the time spent searching for them and reducing traffic congestion. The development of a web application was proposed to complete the implementation part of the study using trained neural networks to provide a useful user interface for displaying available parking spaces. This study aims to open the way to automated parking, predictive parking availability and smart parking systems. Compared to other architectures, the proposed models have demonstrated superior performance, and the effective use of these technologies can improve smart-city practices and reduce the impact of traffic pollution on the environment.

***Key words**: deep learning, image processing, intelligent parking, neural networks, sustainability.*

INTRODUCTION

Technological development has significantly changed modern society by providing useful solutions for critical problems of the environment in which we live. The field of deep learning has witnessed a notable advancement during the preceding period (Boldeanu et al., 2023). Among these, deep learning technologies and object detection architectures stand out as having applications in different fields such as computer vision, medical and smart city. Among these areas, the range of deep learning technologies and models is a key point for intelligent parking systems, having the role of contributing to sustainability and more efficient traffic (An et al., 2022; De Luelmo et al., 2022). Deep learning is a field that involves using neural networks to extract key features from visual data such as images and videos (Lubura et al., 2022). In this context, object detection architectures such as YOLO, Faster R-CNN or RetinaNet stand out, which demonstrate notable performance in the identification and localization of objects from these visual data (Goumiri et al., 2021; Hwang et al., 2023; Xie et al., 2015). Leveraging these features detection models are successfully integrated into traffic monitoring applications, autonomous systems, and smart-city solutions (Gkolias & Vlahogianni, 2019; Gören et al., 2019). A popular area that has brought continuous research in recent years is represented by the implementation of intelligent parking solutions where these models can quickly identify the status of these reference areas (Deruytter & Anckaert, 2013; Ellis et al., 2021). Intelligent parking systems are using video cameras to monitor parking spaces in an efficient way (Amato et al., 2017; Çiçek & Gören, 2020). Based on these, the system manages to capture key visual information that can represent the entry point of deep learning detection models. Based on these monitoring and visual data, the systems can quickly identify available parking spaces in real time, providing drivers with quick data and reducing the time it takes to search for a parking space (Nurullayev & Lee, 2019).

Following these characteristics, intelligent parking systems have a positive impact on sustainability and overall traffic. Reducing the time spent in traffic looking for a parking space reduces fuel consumption, provides safety for drivers, and has a major impact on efficient traffic solutions (Satyanath et al., 2022). Moreover, with the reduction of time spent in traffic, searching for parking, gas emissions that endanger health and the environment are also reduced. In addition, intelligent systems can provide drivers with fast, real-time information, reducing the added stress that comes with congested traffic (Thakur et al., 2023).

These features have the role of managing smart-city solutions by generating real traffic information. The analysis of collected data can bring to the fore not only smart parking solutions but also appropriate measures for the management of heavily trafficked areas, management of parking spaces and sustainable urban development (Ng et al., 2018; Truong et al., 2022).

As technologies evolve and their documentation is well defined, various studies note key features of deep learning to contribute to a sustainable and well-informed future of traffic. Their integration represents areas of ongoing research solving problems as urban areas become increasingly congested and difficult to manage (Hwang et al., 2023; Zhang et al., 2018).

This paper presents the implementation of detection models of the YOLO family for the automatic detection of parking spaces from digital images, an important first step in the development of intelligent systems related to this task. Moreover, the models are optimized to extract important features from the input data, and finally they are tested to export a model capable of making accurate and high-confidence detections. Additionally, a React.js web application is developed to use the trained and validated models in making automatic detections for data uploaded to the web interface.

A solution of this type aims to demonstrate the remarkable performance of deep learning technologies integrated with modern web technologies. Apart from the introductory chapter, chapters are attached that present the materials and methods used for the development of the study, as well as a part of experimental results and discussions that capitalize on the characteristics of the implemented detection models. Finally, the conclusion section presents the key points of the study.

MATERIALS AND METHODS

Implementing an automatic vehicle parking management system using visual data starts with building a large, robust dataset that includes relevant examples so that the detection model presents a solid foundation for training and testing. Following the previously presented characteristics and state-of-the-art analysis, a digital image dataset was collected, using various sources that included open-source datasets and images taken from nearby urban areas (Blanderbuss-Kaggle, 2024). The images in the dataset of the present study are of RGB type and include files with the extension PNG or JPEG, with varying resolutions and illustrating different real-world conditions and contexts.

The total number of images in the dataset is 1100. They have been structured into subfolders that include the information needed to train and evaluate a detection model - training, validation, and testing. The division of the dataset followed a structure of 70% for training (770 images), 20% validation (220 images) and 10% testing (110 images). Each part of the dataset contains the images and annotations relevant to the detection process, the implemented annotation format is YOLO, with files in the .txt extension. They will be attached to the chosen detection model, from the YOLO family, to be presented in this chapter. Example images of the dataset are shown in Figure 1.

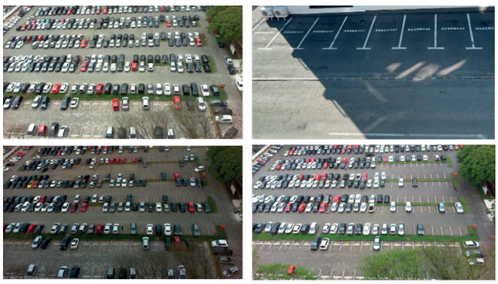

Figure 1. Examples of digital images of the dataset for car parking detection

Starting from the attached examples, it is observed within the dataset variations and various conditions present in the dataset images. The dataset also includes marginal examples with various lighting, blur, contrast conditions to present the detection model with learning examples close to real conditions. The images in the dataset went through an online augmentation process, typical of YOLO models. At the same time, a part of pre-processing was followed so that the size of the input image is the one expected by the used YOLO model - 640x640px.

Online augmentation involves a series of transformations applied to the training data set during the training process of the detection model. These transformations are random and are not applied before the training process, which allows the model to see different examples in each training epoch. This adopted process is essential to increase the detection and generalization ability of the model and included various types of transformations - rotation, scaling, translation, brightness and contrast changes, noise, cutout and mosaic, a type of augmentation that combines 4 images examples that are presented to the model during training.

The detection model chosen for the development of the present study was YOLOv8 (Jocher, 2023), being one of the new, advanced versions of this family (You Only Look Once). The YOLOv8 model brings significant improvements over previous variants and is distinguished by several key features. Studying the code attached to this variant allows the extraction of these key innovations, for the present variant there is no official paper.

YOLOv8 introduces improved backbone and neck architectures. The backbone structure responsible for extracting the information of interest presents changes to the CSP Darknet network. The representative blocks of this Cross-Stage Partial Connections structure improve the flow of useful information to the detection model and significantly reduce the computational complexity footprint. PANet (Path Aggregation Network) represents the basis of the neck structure for a precise detection of objects of various sizes, a module that facilitates the integration of image features at different resolutions. The YOLOv8 capabilities describe the one-stage network detection process characteristic of the YOLO family and are successfully applied for multi-scale detection capabilities similar to state-of-the-art structures such as Feature Pyramid Networks. The head structures of the new YOLOv8 variant are specialized for the classification and regression part and support clear separation of tasks and overall model accuracy. In this way, the predictions are optimized, and the localization and classification of objects is accurate. The architecture improvements also include new optimization techniques at the core, with advanced data augmentation that ultimately brings fast convergence and diverse hardware performance. Tasks for using YOLOv8 include detection, classification, and segmentation of digital images.

The hardware and software part that was the basis of the implementation of the solutions in the present study included a dedicated system with Windows 11 operating system. From a hardware point of view, the system features a dedicated NVIDIA GeForce RTX 4070 8GB video card for the successful management of deep learning architectures, CUDA support, to which is added an Intel Core i7-14700HX CPU, 32 GB RAM, 1 TB SSD. The chosen programming language was Python version 3.10, and the chosen deep learning framework was PyTorch, for the basis of the implementation of the chosen detection architectures, in relation to the YOLOv8 code.

RESULTS AND DISCUSSIONS

This chapter presents the experimental results and discussions based on the performances obtained from the training and evaluation of the detection models. The methodologies and metrics used are exposed throughout this chapter highlighting the strengths and limitations of each proposed model in relation to the attached data set.

For the present work transfer learning and fine-tuning techniques were adopted in using the YOLOv8 model (Jocher, 2023). To describe fast detection systems, the motivation of the present study included choosing optimized models of YOLOv8, small and medium in terms of complexity and export on resource-constrained platforms: YOLOv8 versions n (nano), s (small), and m (medium). For the present case hyperparameter fitting techniques were also pursued. These can have a positive impact on performance and include learning rate, optimal batch size, number of training epochs, early stopping, and size of anchors for detections of various sizes. In principle, a balance between convergence and performance was followed and analyzed. Table 1 shows the detection metrics resulting from model evaluation on the test dataset, with new images from the previously presented dataset split. Based on these test images, the best saved weights of each model are run to observe the behavior on new data.

Table 1. Parking lot detection performance on the test set (ALL Class)

Model	Precision	Recall	mAP@50	mAP@50:95
YOLOv8n	0.977	0.935	0.974	0.810
YOLOv8s	0.971	0.952	0.956	0.780
YOLOv8m	0.959	0.964	0.983	0.809

Version 8.2 of the YOLOv8 model was used from the base of the ultralytics library (Jocher, 2023) that supports this part of the code. The optimizer was AdamW with a learning rate of 0.00125 and momentum 0.9. The number of epochs was 500. The models were evaluated using common object detection metrics: Precision, Recall, and IoU (Intersection Over Union) for calculating mAP@50, mAP@50:95.
The composition of the dataset presents two reference classes, related to the availability of parking spaces: free or occupied, with the annotations created and attached to each image of the dataset. A class called “ALL” is typical for detection tasks in relation to the YOLO family model and involves an averaging of the results obtained for each class separately, treating them with equal importance and defining a common point for evaluating the overall performances, the model being trained to recognize correct the two availability statuses in the illustration of the parking spaces.
According to the metrics obtained (Table 1), the models implemented for the present study achieve remarkable results. The characteristics and performances demonstrated are based on the settings attached to the training and evaluation steps. The evolution of the metrics for these cases are presented in Figures 2, 3 and 4, graphs resulting from the YOLOv8 code and organized in the typical YOLO format.
The first chosen model, YOLOv8n, describes a good performance in terms of accuracy and mAP@50, and highlights the model's ability to detect available parking spaces, generating few false detections. Outside of these metrics, recall is lower compared to the other models, missing instances of interest. YOLOv8s presents itself as a balanced model in terms of Precision and Recall. This notes that the model is quite good at correctly detecting parking spaces and minimizing false detection errors. However, mAP@50:95 is lower with poor performance over a wide range of precision-recall and at different IoU thresholds. YOLOv8m is the model with the highest recall value, indicating the remarkable performance of the model in detecting parking spaces. However, the accuracy value decreases indicating that the model may generate more false predictions, but the model shows superior performance in terms of overall accuracy.
Each model implemented presented weaknesses and strengths. YOLOv8m can be noted as the top model with high overall accuracy and good coverage marked by the highest recall. YOLOv8n is good in terms of precision, while YOLOv8s is the most balanced model implemented. The choice of the desired, optimal model depends on the characteristics of the application for which these deep learning models are implemented, based on prioritization of various categories: hardware, general accuracy, maximum accuracy, or detection speed.
The context presented in the dataset illustrates areas with parking spaces starting from favorable to slightly unfavorable environmental conditions. As a first step in the further development of the present work, it is desired to collect data that complements the existing data set with a series of unfavorable conditions, which could make such implemented detection models difficult. The motivation for this is related to testing in various conditions that can successfully cover detection systems that want to respond even in the most difficult conditions, without being affected by false detections.
According to the study carried out, a series of limitations of the implemented models were observed that contribute to the decrease in performance. First, there is a small problem of detecting dark-colored cars occupying parking spaces, which often do not have clearly visible details to result in correct detections. This is because the color of the material paving the parking areas is similar.

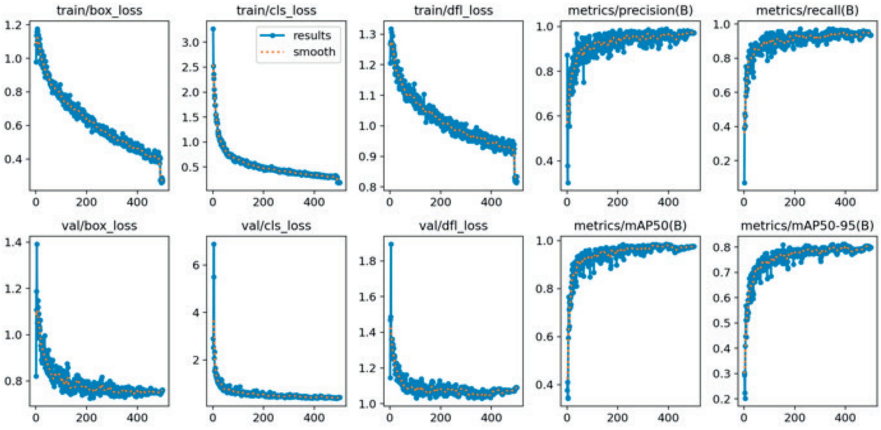

Figure 2. YOLOv8n training and validation results

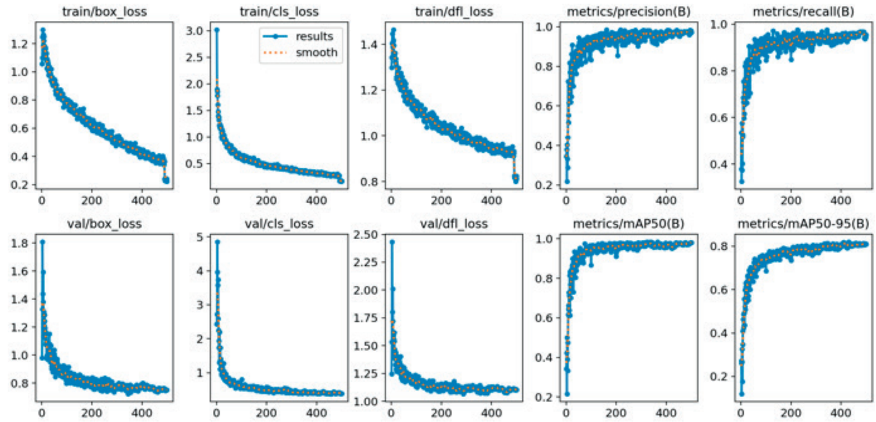

Figure 3. YOLOv8s training and validation results

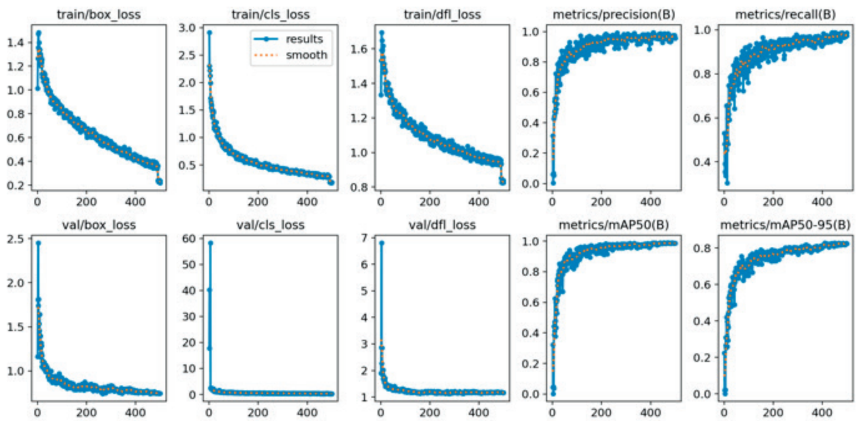

Figure 4. YOLOv8m training and validation results

Another problem is described by false detections of models arising from inappropriate parking lots, with vehicles parked in two or more spaces or vehicles oriented differently. The detection model was observed to be very reliable in predictions of where parking spaces are correctly occupied and the (usually white) boundary lines are clearly visible. Other problems observed are in the case of shaded areas, partially or totally covered by objects other than those of vehicles, and parking lots with blurred or hardly visible boundary lines. For these marginal cases the data set can be supplemented later, and the models re-trained accordingly. At the same time, the models can be adapted to define these cases, for better management of parking spaces and for their quick identification and release. With all these characteristics, the present study marks an initial direction of solid development, with satisfactory results, which finally support the performance of deep learning in such tasks, useful for the management of public or private parking lots and urban traffic.

CONCLUSIONS

Deep learning, especially detection models based on convolutional neural networks, demonstrate remarkable performance in the detection and estimation of the state of parking spaces as part of intelligent systems. Manually inspecting parking spaces using authorized personnel is expensive and time-consuming. In this sense, the development of deep learning solutions for automatic detection and continuous monitoring represents key points of research and development.

In the present work, three optimized models of the YOLOv8 architecture were implemented for automated parking detection. The obtained results demonstrate the effectiveness of these implementations and open the way to new research directions, in the direction of automatic parking management and monitoring systems. The performances obtained were based on a carefully collected and annotated data set that tends to illustrate the various conditions that may be present in real scenarios. Key metrics demonstrated Precision and mAP@50 values above 95%, recall values between 92-96% and overall mAP@50:95 performance above 75%.

The optimization of the chosen detection models using transfer learning techniques, fine-tuning and the adoption of online augmentation, had a positive impact on the obtained performances.

However, there are limitations and observations that emerge from the performances obtained and prove critical steps through which the study carried out can be developed further, to be adapted to different environmental conditions. The collected data set can be increased by adding new scenarios and areas to analyze the ability of the detection models in much more complicated scenarios, as often happens in real cases. Detection models can be improved by integrating new key feature capture modules and can pursue their implementation in lightweight platforms to create autonomous systems, testing the speed of inference and detection. However, the performances obtained are notable and can be seen as important research that can materialize in customer-oriented, sustainability and smart-city systems.

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