Implementation of Vision Based Approach for Adaptive Parking Lots Occupancy Estimation

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ABSTRACT:

This paper written by I. Masmoudi and A. Wali, introduces new techniques for improving the estimation of parking lot occupancy by considering the adaptive volume of a parking lot. The approach, described in their paper is an improvement upon their earlier proposal where they outlined a vision-based system for parking lot detection [1]. This piece expands on the original ideas to account for vehicles of various dimensions and the necessity of clearly visible parking lines. As well, by including an adaptability component, they reported higher accuracy for ‘bumper-to-bumper’ or curb-side parking along city street as well as in lots.

Complementing their results, the authors discussed a real-world user-facing architecture where drivers can be directed to available parking spaces based on their preferences. While we were unable to implement their design due to time constraints and lack of relevant details, it is an impactful application worth discussing.

The results presented by the authors imply noticeable improvement compared to related proposals and their previous implementation. For this report we will present their findings and adaptive strategy, but significant implementation details were missing from the paper. So, we will also include an original method for training based on the VIRAT dataset using Convolutional neural networks as an alternative.

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INTRODUCTION

Ever since the introduction of suburban development projects around the globe, primarily in western and European societies, the presence of automotive vehicles has dramatically increased to facilitate the transportation of citizens from their sprawled suburbs to denser urban cores. Furthermore, more and more families are becoming dependent on personal automotive transportation to navigate their local communities or traverse larger distances.

As personal vehicles become an ever more present part of our lives, an increasing number of drivers are demanding available parking in and around their destination (Figure 1). However parking comes at a steep covert cost. In the U.K., for example, “Parking … made up almost a third of the total cost of motoring… On average, U.K. drivers are spending almost £2,000 a year on parking-related costs.” As reported by Dr. Graham Cookson, Chief Economist, INRIX [2]. Denser cores of the United States have similar direct and indirect costs associated with parking leading to excessive waste in fuel, time, and money [3].

Chart, bar chart

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Figure 1:Registered Vehicles in the US

1A: Motivation

The authors’ proposed solution is aimed at reducing the effective waste arising from drivers looking for parking when arriving at their destination. If drivers could immediately identify available parking spaces without the need to comb through city streets or congested parking lots, we could potentially observe a severe decrease is needless resource consumption. Furthermore, an integrated solution into existing mobile devices could make commutes less stressful overall.

The indirect problems associated with parking could potentially be curbed if a more convenient solution was offered to drivers. Illegal parking is a major concern for dwellers in dense urban areas because it can interfere with local traffic operations such as construction, commercial delivery, and emergency response [4]. If drivers knew of available parking near their destination, they would be more inclined to avoid illegal spaces at the risk of receiving an infraction or impeding services the local community depends on. While also having the potential to improve other implicit detriments such as traffic congestion and/or risk of accidents to other drivers.

The demand for more vehicles consequently leads to an increased demand for parking, a symptom of which is the emerging industry of parking management. Consumers are demanding more lucrative and holistic solutions to their parking woes signaled by the valuation of the parking management industry expected to exceed $10 billion in valuation by 2030 [5].

1B: Problem Statement and Rationale

The demand and market conditions are ripe for a solution to address the inconvenience of searching for vacant parking spots experienced by drivers globally. A proposed solution must address the parking management needs within the private and public sector. Additionally, it must be scalable and flexible enough, so that drivers in various environments can reach parking spaces accommodating to their vehicle size. Drivers from urban cores to sprawled suburban developments are exposed to the problem of lot availability to some degree or another.

Moreover, the solution must navigate drivers to vacant spaces as efficiently as possible. When a driver is guided to an empty space, they are more likely to reduce their fuel consumption and save time. Reliable guidance will possibly incentivize wider consumer adoption leading to greater savings overall. Another benefit is the reduced driver anxiety when it comes to searching for a spot if they know parking is readily available.

Cost effectiveness must be another key feature of a proposed solution to motivate drivers and lot owners to adopt it and further reap the savings. Currently, internet access with mobile devices is the most likely host for such a solution considering as many as 93% of drivers rely on navigation systems today [6].

1C: Objectives

More succinctly, we want a solution that is capable of reliably estimating the occupancy of available parking spaces in a wide variety of environments and scenarios, then direct drivers to those vacancies. Specifically, the solution must apply to private and public spaces while also being:

* Cost effective
* Flexible
* Scalable

The authors I. Masmoudi, A. Wali propose a solution which leverages existing security camera infrastructure to estimate the occupancy of a parking lot, by detecting the entry and exit of a vehicle then adaptively estimating the available occupancy based on the volume of the lot and vehicles. As vehicles enter the lot, the overall volume decreases, conversely, on exit, the volume increases relative to the estimated volume of the exiting vehicle. This approach scales based on existing cameras, is cost effective by not requiring new installation of additional equipment in areas where cameras are already common and can direct drivers to vacancies over the internet.

For our implementation we pivoted away from the original papers’ since it required significant details not cited such as camera calibration and lot count. Instead, our independent research led us to convolutional neural networks as a viable alternative to the methods described by the authors which we will explore it greater detail within section 3.

BACKGROUND MATERIAL

2A: Image Processing Techniques

**Canny Edge Detector:** when determining the motion of vehicles we opted for the famous Canny algorithm for edge detection which includes a horizontal and vertical gradient mapping of the footage in grey scale. With Canny we were able to estimate the change in position of a vehicle by comparing its change in position for its edges frame after frame.

**Guassian Blur:** For the preprocessing of the video footage we applied a mild gaussian blue to smooth out edges and eliminate unnecessary noise in the video footage. The Guassian blur helped tremendously when combined with the Canny edge detector for detecting edges because after smoothing outliers were eliminated and only smooth large images were highlighted.

2B: Video and Image Retrieval and Analysis tool dataset (VIRAT)

The VIRAT dataset offers a variety of high-resolution HD footage taken from different viewing angles, steady frame rates, and in numerous environments [9]. Allowing for robust recognition of multiple events which will lead to a model that can accurately classify events without overfitting. While the authors did not specifically mention the event types they used to train their model, we inferred two event types that were of interest during training for distinguishing the entry and exit of vehicles:

1. Type 5: person getting into a vehicle
2. Type 6: person getting out of a vehicle

To simplify our model training, we assumed that if a person was entering a vehicle, then its likely they would drive away from their spot. Therefore, we associated Type 5 with a vehicle exiting a parking spot. Conversely, if footage was of Type 6, then we assumed a person just parked their car and is about to exit, so we associated this event with a person entering a parking spot.

The popularity of the dataset must be due in part to the immensely helpful documentation and annotations relating to each scene which helped to optimize the extraction of relevant footage from the enormous 35gb of total video data. Each video is annotated with the event type, event location, and relevant frames of the event, so only cropped sections of the video data were considered during our training. Indeed, hardware limitations prevented us from training our model on an entire video sample.

2C: Related Works and Existing Solutions

Method of leveraging existing camera infrastructure to provide parking management solutions with a vision-based approach have risen in popularity recently. The global contribution of authors towards recognizing patterns for improving parking management alludes to the universal gripes experienced by drivers all over the world.

As mentioned earlier, the authors’ previous work in this domain [1] was focused on looking at the homography produced from a fixed view video sample, then subtracting the foreground image in motion (vehicle) from the background image (parking lot) using a Mixture Gaussian Model (MGM). Following this, the authors extracted relevant features using the ‘Speeded up Robust Features’ technique before classifying based on the detected motion of the entering or exiting vehicle. Using this classification, they were able to determine if a vehicle left or entered a parking spot to subsequently increase or decrease the available occupancy. As discussed by the authors, they obtained satisfactory results when a sufficiently accurate homography was obtained, but was limited to specific parking orientations, clearly marked parking lines and did not consider vehicles of different sizes.

Similar work by Bravo et al [10] analyzed outdoor parking footage in clear and inclement weather to determine if a parking spot was vacant or empty. Once a lot was identified, they considered two categories of features: color, and texture (Figure 2). Then, they evaluated the accuracy of various classification techniques such as KNN, ANN, NBC. Their results with SVM were adequate despite unclear samples due to inclement weather, but their model was rigid and was unable to identify whether a space was indeed a parking spot or not. They also mentioned the lack of data was a severe limitation since they needed a wider assortment of samples to avoid overfitting.

Diagram

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Figure 2: Feature extraction techniques based on colour and texture features [10]

In the private sector, there are many trending mobile applications that attempt to provide solutions to parking management woes directly to drivers. Mobile applications like Pay by Phone [11] with its 60 million users, or SpotHero [12] who has served 50 million cars, broker the purchase of privately owned parking lots with drivers. These solutions are convenient, cost effective, and estimate occupancy within privately held spaces based on consumer demand. However, they don’t consider public parking options at all, and the availability of the spaces is dependent on the lot owners management which can be incredibly time consuming for larger lots.

METHODS

It is worth considering the methods described by the authors in their approach. However, this paper is a follow-up in a series of publications exploring different techniques for estimating parking lot occupancy. Therefore, we will restrict the scope of this discussion to the specific novel ideas mentioned within this paper and modestly reference previous works.

Tangentially to the authors ideas, we will mention some of the techniques explored in our implementation to reproduce some of their concepts. However, due to insufficient details our implementation strays from the original authors’ proposal.

3A: Technical Libraries

We dedicate some brief consideration for the open-source libraries used throughout our implementation.

* **NumPy**: an essential pillar or vector and matrix manipulation, we used NumPy as a crucial library for all computations involving numeric matrices.
* **Pandas**: complemented the computational capabilities of NumPy while also provided additional tools for preprocessing data on a larger scale.
* **OpenCV**: is the main tool we used for processing the images including down sampling and converting to grey scale.
* **Sci-Kit Learn**: was instrumental in training our model with all the features necessary to optimize results and improve accuracy as much as possible.
* **MatplotLib**: assisted with visualizing the progression our model and helped point to improvements we could make during implementation.

3B: Adaptive Algorithm

The prerequisite step of the algorithm involves obtaining the geometric camera calibrations parameters (intrinsic and extrinsic) to estimate the real-world size of a parking lot space monitored by a parking agent. A parking row agent (RA) is an entity responsible for monitoring a fixed size lot and detecting vacancies within the “…3D volume contained in its specific configured row.” Its lot is a row of available parking spaces, where the number of available spaces is configured manually as an offline step. The volume of the row it monitors is estimated based on the camera calibrations using techniques such as homography not explicitly mentioned in this publication.

Diagram

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Figure 3: VIA volume estimate relative to RA, and merging [1]

For every car detected within its volume, it assigns a volume agent (VIA) to track the vehicles volume in relation to the total row volume. These individual VIA’s cooperate to increase the accuracy of their volume estimate by merging volumes if their volumes are sufficiently close. In this manner, the RA’s volume is calculated based on its total volume subtracted from the VIAs’ volume. Also, if there is a vacant space between VIAs we can obtain a more accurate estimate of its size and direct drivers as required. The behavior is summarized in the figure below.

Diagram

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Figure 4: Adaptive estimation of the occupied volumes [1]

With this agent assignment and merging strategy, the row agent can adapt its volume based on the entry, exit and size of vehicles that are occupying a parking lot. This is incredibly beneficial for environments where the parking lines are not discernible. Another incredible benefit of this approach is the ability to distinguish among vehicles of different sizes, catering to all types of vehicles including motorcycles and large trucks.

3C: Code Details

Our implementation strays away from the authors original proposal due to insufficient details with their design. However, we attempted to detect the entry and exit of vehicles within a parking space using image processing techniques. On execution, the user is required to manually draw the parking spaces visible within the sample video. This step is analogous to the authors’ prerequisite offline step of manually selecting the number of parking spaces for each camera which will be considered in their algorithm.

Once the prerequisite steps are complete the location of the vehicles in the camera footage is stored for processing. A gaussian blur followed by a canny edge detector is applied to the footage to map out the vehicles present. As the footage continues, we can detect the motion of vehicles exiting or entering the space. When the motion of vehicles overlaps with the location of a parking space we can reasonably assume the space is occupied. Our algorithm also ignores the presence of people walking or irrelevant motion to avoid false positives.

This approach poses some limitations if the parking spaces are obstructed by foreign objects such as poles or fire hydrants, the overlap of can be wrongly detected. The camera sway or vibration can simulate motion in the canny edge detector causing some false positives depending on the quality and stability of the footage. Similarly, the detection of motion is dependent on the angle and type of video. The samples with the highest accuracy had high visibility, good lighting, a wide aerial view, and the 2D projection of the parking spaces are relatively the same size. Lastly, due to the prerequisite human interaction to decide the parking locations, this can pose a possibility of human induced error especially in crowded areas where the presence of parking is not easily distinguishable.

A group of cars on a road

Description automatically generated with low confidence

A picture containing outdoor

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Figure 5: Best results when applied to a sample with a good aerial angle, and well spaced lots

RESULTS

4A: Our Results

When we had samples that adhered to our optimal cases our accuracy was satisfactory. For the test sample below we obtained a 73% accuracy, however more testing in necessary for sub-optimal samples to improve our implementation and lead to a stronger accuracy figure.

Table

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Figure 6: accuracy, precision, recall, F1-Score for sample video footage

4B: Authors’ Results

The authors highlight the robustness of adding adaptability to their existing parking detection by citing two new cases where they achieved a suitable accuracy measure for cars parked along a curb (91.2%) and when parking lines were not clearly visible (88.9%) summarized in the table below.

Table

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Figure 7: Performance under different on street dispositions [1]

Furthermore, adding adaptability led to a marginal increase in F-Measure compared to previous authors’ works.

Table

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Figure 8: Comparative study of performance [1]

Based on these figures, adding the adaptive algorithm, as recommended by the authors, will lead to more accurate results for optimal cases when parking lines are clearly drawn, and visibility is good. As well as cases when the orientation of the parking is ‘bumper-to-bumper’ or curbside, and lines are not visible.

5: Conclusions and Future Work

When analyzing this publication, we were disappointed that critical information was omitted, making it impossible to reproduce with our own implementation. Nevertheless, there were some promising improvements the authors cited when compared to previous work they have published surrounding the topic of parking management with vision-based techniques.

5A: Applications (Architecture)

Based on the potential of the findings of this publication we can begin to conceptualize an architecture meant to navigate drivers to vacant spots over the internet. The authors propose a user facing mobile interface where drivers can input their parking preferences based on the size of the vehicle they are driving and their geographic destination and return a parking spot within reasonable distance.

In this architecture, the parking agents monitoring the parking spots are constantly updating the occupancy based on motion triggered camera footage. The occupancy is forwarded to a centralized server which can interpret the overall occupancy of an area and know exactly which spots are available for a driver. With the geographic positioning of the camera and the driver’s location, they can be navigated to the open spots. Once they arrive, the occupancy of the lot is updated by the agents again.

With the advent of commercially available IP cameras, a centralized guidance system for driver direction can be conceivably built without the installation of new hardware components. IP cameras are already linked to a central server unit within the same network, so all the footage is centralized over the internet. Exploiting this system to consumers is an inherent flaw in this design and poses severe security weaknesses especially when applied to the public sector.

Graphical user interface, diagram, application

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Figure 9: Example User Facing Architecture

5B: Limitations:

Considerable limitations were faced when considering the publications findings. Firstly, they failed to mention how they obtained the camera calibration information from the VIRAT Dataset. When examining the latest 2.0 release of the dataset, the included documentation made no mention of intrinsic or extrinsic parameters for the cameras capturing the footage. Therefore, the authors statement that “…the [VIRAT] database provides also for each one its corresponding camera matrix to ensure mapping from the image coordinates to the scene dependent world coordinates.” Is completely unverifiable.

The solution proposed in this paper was trained using the VIRAT dataset, however this dataset contains only footage from clear days with high visibility. Therefore, it is challenging to verify the performance of the authors’ model in inclement weather such as: rain, snow, or fog. Similarly, it is equally challenging to evaluate its performance during evening or low light environments because the VIRAT dataset does not have footage from these scenarios.

The 3D modeling approach taken by the authors has some limitations when the parking spaces are interrupted by foreign objects such as fire hydrants, or pillars. When an object is in the way, the total volume could be undesirably split up leading to further errors with occupancy estimation.

Lastly, the prerequisite steps for their solution are exhaustive. They include:

* camera calibration for each parking agent
* manually identifying the different parking spaces to be considered. As the authors specify: “This is an off-line step which is necessary to be achieved once while installing the system in a new parking station.”

5C: Suggested Improvements

Improvements to curb some of the solutions limitations are paramount for it to become widely adopted in the private or public sector. The dataset used for training, must be supplemented with footage during harsh weather, low light environments, and evenings. This will help to improve the classification of the occupancy of the proposed model during these scenarios, like the approach of Bravo et al [10].

If a parking space is obstructed by a foreign object, the algorithm should be able to recognize it and exclude it from the 3d volume estimation. In this case, real-world validation may be necessary to check the presence of such objects.

5D: Concluding Statements:

While the results delivered by the authors appear promising and supplementing their previous work with the adaptive occupancy estimation algorithm helped improve their accuracy, the paper lacked sufficient details for reproducibility. As well, the prerequisite steps involved are far too exhaustive to be applicable in the private or public sector yet. Lastly, the robustness of their solution should be explored with footage from a larger pool of environments and situations.

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