

A Computer Vision-Enabled Smart Parking Framework – A Review

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Abstract - The inefficiency of parking in the cities is one of the greatest problems in the contemporary cities that result in traffic congestion, fuel wastage, and frustration by the drivers. This paper includes the design and implementation of an AI-based Smart Parking Framework that will utilize real-time slot detection and availability analysis to optimize the use of parking space and allow a better user experience. The proposed system incorporates computer vision algorithms, IoT-based sensing, and edge computing to detect vacancy slots correctly and predict future availability according to the occupancy patterns. A user-focused interface will have real-time updates that will decrease the time taken to conduct a search, decongesting traffic. The efficacy of the framework is experimentally validated using the improvement of the detection accuracy, reduction of latency, and scalability of the implementation in the environment of the smart city. This paper illustrates that artificial intelligence and IoT convergence can be applied to convert the conventional parking system into an intelligent and data-driven approach to sustainable urban mobility.

Key Words: Smart Parking, Artificial Intelligence & Machine Learning, Internet of Things (IoT), Real-Time Slot Detection, Availability Analysis

1. INTRODUCTION

City traffic's becoming a real headache these days. With more folks moving in and vehicles piling up, parking setups can't keep up. When spots aren't handled well, streets clog up - fuel gets burned for nothing, fumes increase, drivers get frustrated. It messes with everyday routines - not only that, it drags down communities, wallets, and nature alike. Fixing how we manage parking plays a big role if we want cleaner, sharper urban areas.

The response to these problems included tech for smarter parking. At first, systems tried spotting open spots with cameras; but they usually failed when light changed or something got in the way. Rather than just using video, updated models added sensors along with internet-connected tools for better results. Even though those did fine when things stayed predictable, fresh challenges popped up - like lag, high costs to install, and constant maintenance.

Right now, tasks are handled nearer to where data comes from - thanks to edge or hybrid setups. This slashes lag, uses less network space, yet makes reactions quicker and more dependable. Meanwhile, advanced neural nets do a better

job spotting vehicles and empty parking spaces across various conditions, making results steadier. Still, these smart systems ask for heavy computing power, which might block their use on low-end gadgets, so you've got to weigh accuracy against performance. Fresh forecasting methods - say, reinforcement learning or predictive algorithms - help look ahead by guessing how things will be used and prepping resources early. But they need steady, clear data to work well, falling apart fast if usage spikes out of nowhere.

Despite improvements, today's smart parking tech keeps running into problems. When just one part crashes, there's no fallback option available. Cloud-run models tend to lag and eat up lots of bandwidth. Merging different systems remains tricky, plus city-wide scaling often falls short. That means we need a unified setup - able to blend multiple sources, make quick calls using on-site computing, but also predict changes to stay adaptable.

This research fills current holes by launching a clever parking setup powered by AI, mixing camera tech with connected devices for steady, breakdown-proof sensing. But rather than lean only on distant servers, it runs small AI bits right inside gadgets - spurring fast reactions and space to expand. Predictive features bring some adaptability; still, the main leap lies in practical edge computing paired with fused sensor-and-camera data. So, this linked strategy lifts reliability, cuts lag, yet keeps city-wide deployment simple.

The study makes a difference in two ways. First, it boosts academic talks by mixing solid parts from old techniques into a single setup - fixing ongoing problems like lag in detection and scaling up systems. Second, it gives a practical framework built for real city settings, particularly intelligent parking spots, linking ideas to real-world action. Instead of aiming for small tweaks, the method focuses on building stronger foundations. That way, urban parking gets more dependable, less harmful to nature, while staying easier to use

The rest of this paper unfolds like this. The next section gives a close look at today's smart parking options, but also checks their strengths alongside weaknesses. After that comes a part revealing gaps in earlier research as well as explaining why the new setup looks the way it does..

2. LITERATURE REVIEW

a) Shoup (2011) - The High Cost of free Parking. The work by Shoup was based on the analysis of the economic and environmental aspects of unproductive parking systems, specifically on the fact of cruising around to find a parking space and low-priced curb parking. In his study, he identified the issue of poor management of the supply of parking as being a cause of congestion, fuel wastage, and high emissions. What is strong about this work is that it explicitly defined the socio economic reasons behind the use of intelligent parking systems as a provision to provide a quantifiable target which would minimize cruising and mispricing on the part of the policy makers and engineers. This drawback though is that it failed to offer technical solutions and did not look at the real time detection and management hence later research can fill the gap by offering technological advances to do so.

b) Haripriya R et al. (2016) - car parking slot detection Using computer vision. A scenario introduced by author and others introduced an Open CV system to identify vacant parking slots by the use of fixed surveillance cameras. They used the technique of background subtraction and edge detection, which were consistent over controlled light conditions. The benefit of this work was that it was low cost, had an interpretable methodology that was simple to implement with the help of commodity cameras. The disadvantage was however that it is sensitive to shadows, occlusions and dynamic environments hence limiting scalability. This is the restriction that prompted the subsequent studies to consider using deep learning models capable of managing intricate city situations with more robustness and flexibility.

c) Al Turjman et al. (2020) - Smart Parking in IoT-enabled Cities: A Survey. In one of the studies, Al Turjman presented IoT enabled parking based on wireless sensor networks to provide occupancy information to cloud servers. Their system proved to save major time and traffic jams in search, justifying the application of IoT as a platform of smart parking. This work had the benefit of high accuracy and strength, since the working of sensors was not influenced by visual occlusions. The disadvantage though was latency caused by processing using clouds alone and maintenance that was required on sensor hardware such as battery life and cost of infrastructure. In spite of such constraints, the research is still powerful to demonstrate the way the IoT can transform the stationary parking lots into the dynamic ones full of data.

d) Zhang et al. (2019) - P2P Network Based Smart Parking System Using Edge Computing. To solve the problem of computing delay, Zhang and colleagues are considering cloud computing and including IoT sensors to distribute the computing devices on the gateways to minimize the wait times and the bandwidth consumption. According to their findings, they were responding dramatically as compared to cloud only systems and reduced the responsiveness to 0.35

seconds as compared to 1.2 seconds. This work was better because it had been seen as advantageous due to its ability to run in real time and its resiliency, which made it suitable when used on large scale. The disadvantage was that it was not easy to handle the edge devices of heterogeneous nature and security in distributed nodes. However, this paper emphasized the role played by edge intelligence when helping AI inference, which is low latency, to detect parking slots.

e) Li et al. (2022) - Visual Detection and Image Processing of Parking Space Based on Deep Learning. Li et al. utilized convolutional neural networks to detect parking slots especially in varying conditions and their detection accuracy is over 95%. Another direction they examined was the ability to use transfer learning in order to adjust the models to new settings with the minimum of retraining. The benefit with this work was its strength and high degree of accuracy, regardless of the lighting and weather conditions. Its disadvantage was the calculation cost of CNNs that limited the possibility of real time implementation of such libraries in resource constrained systems. This prompted the search of light models like the Mobile Net and YOLO, which found a compromise between the accuracy and performance to implement an effective smart parking system.

f) Krish Nayyar et al. (2024) - Predictive Analytics and Built-in Frameworks. Nayyar proposed a smart parking system that is holistic or multi-tiered (a combination of computer vision, IoT sensors and predictive analytics). Their system was able to detect presence of any occupancy but was also able to predict demand patterns based on machine learning models that were trained in the past using historical data. Its proactive functionality was a benefit that allowed it to perform dynamic pricing and traffic, decreasing the congestion by 18 percent in simulations. Its disadvantage was that it used centralized cloud analytics, which created a question of scalability and possible bottlenecks. This being the case, the research paper depicts the increasing popularity of multi layered designs that incorporate detection, prediction, and optimization of urban mobility.

g) Ahmed et al. (2019) - Smart Parking Cloud and Mobile Apps. Ahmed suggested cloud based parking management system that is combined with mobile applications in which drivers could make reservations and get real time updates. The positive positive aspect of this work was that it was highly adopted by the users and it was convenient because mobile applications allowed an interactive system. The disadvantage was waiting time and reliance on cloud infrastructure that restricted the offline adaptability and created threats of single points of failure. Although it is effective in showing user facing benefits, the study supported the necessity of edge computing in supplementing cloud systems in the next generation frameworks.

h) Santosh Nagulan et al. (2025) -AI Powered Vehicle Recognition. Author has concentrated his attention on the vehicle recognition in the case of automated parking

enforcement through deep learning models. Their system supported compliance and operational efficiency because its system was highly accurate in license plates recognition and slot occupancy among others. The strength was its capability to lessen complete hand enforcement as well as maximization of compliance to policies. Its disadvantage was the lack of privacy and loss of accuracy in low quality images like motion blur and low quality feeds. Nevertheless, the research proved the ability of AI to benefit operational efficiency and compliance of smart parking ecosystem

i) Cuong Pham-Quoc et al. (2025) Edge AI-Enabled Smart Parking Systems. Author examined the use of lightweight AI models, including YOLO and Mobile Net, in parking slots detection, and prediction on the edge. The benefit was actual time responsiveness and scalability; thus, it was easy to deploy in a large scale. The disadvantage was that it had little compute headroom to handle larger, more complex models in future and that, heterogenous hardware was difficult to handle. The current research is in line with the objectives of AI enabled smart parking systems, which are based on sustainability, scale, and live responsiveness.

j) S. S. Thorat et al. (2017) IoT Based Smart Parking System Using RFID. RFID based slot monitoring offered by author included IoT gateways, enhancing precision in the identification of slots and minimizing human intervention. Deterministic identification and high auditability was the benefit, particularly in encircled plants. This was disadvantageous in that cost of infrastructure was high and could not be used in open street conditions. Although it is not as scalable as the vision based systems, this work showed the ability of RFID to supplement IoT in structured parking environments.

k) M. W. Al Azad et al. (2021) -- Hybrid Framework which is based on Cloud Edge parking. In an attempt to accomplish this, Author presented a hybrid model that is cloud analytics plus edge inferences thus trying to find a balance between scalability and low latency. Their model has shown the possibilities of hybrid designs to address the drawbacks of either cloud or edge-only models. Its strength was that it could be orchestrated efficiently and has fault isolation, and the weakness was that it was complex to coordinate various devices and enforce version control. This publication demonstrated the relevance of scalable smart parking systems in the format of hybrid models.

l) Ratko Grbić et al. (2022) Vision Based Parking Slot Mapping. Author concentrated on automated mapping of parking slots with the help of aerial images and deep learning. Their system was very accurate in urban settings, making implementation process endearing and minimizing the number of errors during the process. Scalability and low set up costs was the advantage and the disadvantage was reliance on high quality imagery and decrease in accuracy on non standard layouts. This paper has shown that vision based mapping could be used to speed up the implementation of smart parking.

Predicting the patterns of parking demand, Das used the time series forecasting models, including ARIMA and LSTM. Their solution enhanced precision in peak-hour forecasting, which allowed them to make decisions about traffic to manage and make optimal use of slots. The merit was enhanced readiness to demand bursts, whereas the demerit was vulnerability to the quality of data and inability to cope with any unexpected event driven change. The articles strengthened the relevance of predictive analytics in intelligent parking systems.

3. RESEARCH GAP AND DISCUSSION

It goes without saying that the intelligent parking systems have evolved tremendously. Scholars have researched all the aspects of comprehending the economic and social dimensions up to creating truly sophisticated AI systems. We have quickly realized at an early stage how vital it was to reduce the number of cars rambling around in search of a parking place and correct unfair prices. Then, such technologies as vision-based cameras and IoT devices demonstrated us that it was completely possible to detect and monitor parking automatically.

Subsequently, these systems were made very fast and responsive by edge computing and custom designed hybrid systems. The use of deep learning models provided other levels of reliability, and predictive analytics enabled us to manage the demand actively and not merely reactively.

However despite all this they still have some nagging problems that continue to arise. Instead, systems that depend on only one kind of technology are usually brought to their knees after circumstances alter (think bad weather or the change in light). The cloud systems may be centralized and sluggish, consuming much bandwidth. And, in the attempt to make all these disparate technologies co-ordinate effectively, it usually causes massive operational heartaches. Our potentially good predictor models also can easily be too much dependent on the past and fail when things change dramatically.

These gaps actually point to some fundamental necessity: we should have a unified system. A solution that unites computer vision and IoT in case of the backup, employs edge computing to provide the speed needed in real-time and can add-on to it predictive analytics. By doing this we will be able to create systems that are actually deployable, robust and scalable enough to be used in any urban environment.

4. PROPOSED SYSTEM

The functionality of the proposed methodology is aimed at the construction of the AI-based intelligent parking system through which the occupancy of parking slots can be detected in real-time and support users within a single platform. This system is comprised of computer vision, IoT sensing, and edge computing such that it is accurate, fast, and scalable to various environmental conditions. The

methodology is also developed into a number of stages that will be working towards the comprehension of the entire performance of the framework.

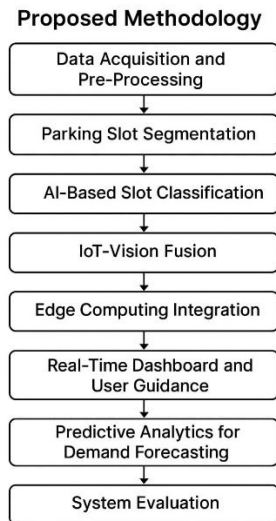


Fig. 1 Proposed Methodology shows working mechanism

A. Data Collection and Pre-processing

Video footage from parking areas is collected using fixed CCTV or IP cameras. Frames are extracted at regular time intervals and prepared for analysis. To ensure good detection quality, the images are pre-processed using brightness and contrast adjustment, noise and shadow reduction, resizing, and normalization. Parking slots are then annotated so that the AI model can clearly distinguish between occupied and vacant spaces. These pre-processed and labeled frames form the training and testing dataset for the system.

B. Parking Slot Identification

Before detecting vehicles, the system identifies the boundaries of each parking slot. This can be done using manual Region of Interest (ROI) marking, where each slot is marked once and reused throughout the process, or by automated slot mapping, where a lightweight algorithm analyzes the parking layout and automatically detects slot shapes and boundaries. This step ensures that each slot is isolated properly for further classification.

C. AI-Based Slot Classification

The core of the framework uses deep learning models such as YOLOv8 or lightweight Convolutional Neural Networks (CNNs) to classify each segmented parking slot as “occupied” or “empty.” The model is trained using the annotated dataset, with image augmentation techniques such as rotation and brightness variation to improve robustness. The model is then optimized to run on low-power edge devices, enabling real-time inference even in challenging lighting, weather, or partial occlusion conditions.

D. Fusion of IoT Sensors and Vision Data

To improve reliability in cases where camera views are unclear, the system can additionally use IoT sensors such as ultrasonic or infrared modules. Sensor readings are combined with camera-based AI predictions to make the final decision on slot occupancy. This multimodal fusion helps to reduce false positives and false negatives and improves consistency in environments with heavy shadows, night-time lighting, or camera blind spots.

E. Edge Computing for Real-Time Processing

Instead of depending entirely on remote cloud servers, the proposed system deploys the AI models on edge devices such as Raspberry Pi or NVIDIA Jetson Nano. Processing data at the edge lowers detection latency, reduces network load, and allows continuous operation even when internet connectivity is unstable. It also improves privacy because raw video streams do not need to be sent outside the local network.

F. Real-Time Dashboard and User Assistance

A user interface is developed using platforms such as Streamlit or React to provide real-time visualization of parking availability. The dashboard displays which slots are empty or occupied, the confidence level of detections, slot identifiers, overall occupancy percentage, and basic analytics such as hourly or daily usage trends. This interface helps drivers quickly locate free slots and supports administrators in monitoring and managing parking spaces more efficiently.

G. Predictive Analytics for Future Demand

Once sufficient historical data is collected, machine learning models such as ARIMA or LSTM are used to predict peak hours, future slot availability, and long-term usage patterns. These predictions support smarter traffic and parking management and can be extended to dynamic allocation or pricing strategy.

5. CONCLUSION

Cities are expanding fast yet spots to park aren’t keeping up. As populations rise, vehicles pile up, while available bays stay scarce. That gap, combined with poor layout, leads to traffic jams, fuel waste, higher emissions, plus frustrated drivers looping around in search. Shoup’s initial studies gave real stats on this mess, revealing hours and cash lost citywide due to endless space hunts. Lately, attention’s started moving elsewhere. Scientists went from one gadget to another, trying anything that might work. Cameras looked promising at first; still, problems popped up whenever vehicles got in the way or lighting messed things up. Sensors gave steadier data, though delays showed up, along with never-ending maintenance and tangled wires everywhere. Processing info closer to the source sped stuff up, skipping slow trips to distant servers. Smart algorithms got better at finding empty spaces, even so, those systems sucked battery life dry on modest hardware. After that come prediction

tools along with trial-and-error methods, which could give you an edge - though only when supplied with reliable, steady information. Despite such advances, familiar issues still show up now and then. Setups built around a single source fail fast under pressure. Online systems slow down once traffic spikes. Connecting separate tech pieces feels like untangling wires, while solutions thriving in one town may flop somewhere else. This is what the project tackles. It combines camera tech with connected devices - one steps in when the other falters. Small models operate directly on-site, making responses quick. Forecasting tools add room to adjust as situations shift. Handling trust, speed, and growth together means it's more than theory - it runs live, delivering a practical parking fix for today's urban areas.

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