ISSN (Online) 2394-2320

International Journal of Engineering Research in Computer Science and Engineering
(IJERCSE)

Volume 13, Issue 6, June 2026

Smart Parking Management and Vehicle Monitoring System Using OpenCV and Real-Time Computer Vision Techniques

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Abstract— ***A proposed intelligent college parking management and vehicle monitoring system based on openCV and real-time computer vision methods is suggested to solve the problem of parking congestion, poor space utilization and security issues in college campuses. By utilizing live video streams of surveillance cameras, the system will automatically identify, classify and track vehicles entering and leaving parking lots through image processing and image detection algorithms based on deep learning. Real time frame processing, vehicle counting, number plate recognition and occupancy is done using Open CV which allows proper identification of available parking slots. The system will offer dynamic parking status, minimize manual operation, minimize traffic congestion, and promote campus security through unauthorized and suspicious vehicle activity detection. The solution is designed to provide efficiency in managing parking and enhance user experience as well as scalable deployment of smart campus environments by use of real time analytics and an intelligent monitoring framework.***

Keywords: Automated parking system, College parking management, Computer vision, Image processing, OpenCV, Real-time vehicle monitoring, Smart campus, Vehicle detection.

I. INTRODUCTION

The modern academic setting is being digitalised, and incorporation of smart technologies is not a choice anymore but a prerequisite to effective work process and safety on campuses. The management of parking facilities in the modern college campuses is one of the most serious issues in terms of infrastructure. Conventional ways of parking control usually involve manual ticketing, physical controls, and human supervision which are likely to be inefficient, error prone, and unresponsive in real-time. The solution to these systemic issues is the suggested Intelligent College Parking Management and Vehicle Monitoring System that exploits the intersection of Data Science, Artificial Intelligence (AI), and Computer Vision. The system enables automated vehicle identification, classification, and surveillance of vehicles entering and leaving the parking grounds by deploying the live video feeds of the surveillance cameras to operate advanced image processing and deep learning-based object detection algorithms to perform the tasks of detecting and classifying objects in the video feeds and tracking them through the parking area.

This system is explained by the interdisciplinary nature of Data Science. The name of Data Science was historically dated back to 1974 when Peter Naur suggested it as an alternative to computer science. This has greatly developed as it was featured by the International Federation of Classification Societies in 1996, and later became mainstream in 2008 by the work of D.J. Patil and Jeff Hammerbacher at LinkedIn and Facebook. Data Science is a mix of knowledge in the field, understanding of programming, and insights of mathematics to identify meaningful trends in crude and unformatted data. When it comes to smart parking, it means processing strain loads of visual information to unveil concealed clues about the occupancy of the parking spots and traffic patterns, which are crucial in creating the institutional decisions.

The human intelligence processes can be simulated by machines through the use of Artificial Intelligence which acts as the cognitive layer of the system. By definition, AI refers to the question of intelligent agents who understand their surroundings and act in ways that increase their chance of reaching certain objectives. Machine vision and expert systems that are capable of recognizing the vehicles and determining the availability of parking are also part of the application of AI to this parking system. Interestingly, when the tasks become routine, like optical character recognition (OCR), they are frequently not listed among the definitions of AI, so-called, the AI effect. This system uses AI cognitive functions, such as learning (acquiring data and building algorithmic rules), reasoning (selecting the appropriate algorithm to achieve a desired result), and self-correction (refining algorithms to get the correct results).

Deep Learning, which is a subdivision of machine learning and is grounded on artificial neural networks, is the particular mechanism that allows the emulation of the hierarchical concept representation that the human brain exhibits. As compared to biological neural networks in human beings where there are about 100 billion neurons interlinked with thousands of neighbors, artificial neural networks (ANN) develop a simplified version of the network in terms of nodes through input, outputs, and hidden layers. Such deep learning architectures as Convolutional Neural Networks (CNN) permit sequential derivation of higher level features of raw input. An example is in parking monitoring, lower layers can detect the sides of a car, but higher levels can detect the type of car, or the alpha numeric digits on a license plate. This intelligent is executed with the help of OpenCV (Open Source Computer Vision Library) which enables real-time processing of the frame, the counting of vehicles and number plate recognition so that the correct identification of the available slots is accomplished with minimum human intervention.

II. BACKGROUND AND MOTIVATION

The main reason to create an automated vehicle monitoring system is the nature of the current nighttime detection technologies that is limited in nature. There is a common problem with limitations of lighting in the current systems where the visibility of the vehicle is highly impaired. Recent studies have tried to solve this with multi-granularity detection systems that dynamically switch in and out of bounding-box-based (when the vehicle is mostly visible) and point-based-based representations (when only location can be discerned in the rural or unlit environment). Even with a mean Average Precision (mAP) of 0.7134 with BDD100K and 0.6621 with PVDN, these systems suffer because of high computational complexity and large demands in terms of GPU resources, which are hard to practicalize in a college setting with limited budgets.

More so, the current campus parking systems are usually typified by high levels of congestion and poor use of space. Manual surveillance cannot offer dynamic and real-time information to drivers hence causing traffic jams as cars go round the campus looking for open parking spaces. The security issues also come about because it is difficult to track the activities of unauthorized/suspicious vehicles during the post-hours. The aspect of human intervention gives the accuracy and security a limit, whereby manual logs are likely to be inaccurate and incomplete. This project is driven by the need to develop a system that can not only track vehicles when they move but also their history and dynamic monitoring of occupancy of the parking slots and alerts in real-time of a violation such as illegal parking or overspeeding on the campus.

Moving toward a more intelligent campus setting requires a solution that should not only be cost effective, but also scalable. The conventional IoT-based systems tend to use costly sensors per single parking spot and that needs a physical maintenance on a regular basis, as well as, initial investment of capital. In comparison, a vision-based solution with strategically positions cameras is capable of acquiring multiple slots simultaneously to minimize hardware foot print. By combining OpenCV and YOLOv8, there is an advantageous alternative with high performance that can achieve 45.45 FPS, which means that the system is capable of processing live feeds with minimal latency as well. This can be achieved by automation of parking space vacancy detection and the recognition of registered vehicles based on the license plate recognition which provides a holistic solution to the manual labor of campus security staff.

III. RELATED WORK

The recent works in the sphere of parking management suggest the paradigm shift between the physical sensor-related systems and vision-oriented approaches. A survey of parking management systems with the use of OpenCV and image processing as proposed by Krishna and Pachipulusu (2024) highlighted that due to the development of technological improvements in computer vision, the functioning of parking facilities can be automated with the use of real-time monitoring and a license plate scan. Their strategy would be to break down the parking space into blocks and to find the occupancy status of each block to notify the users in an easy to use interface. This study confirmed the existence of such systems that enhance the efficiency of parking systems and minimise traffic congestion in cities by updating information on the availability of slots continuously.

Srivastava et al. (2025) examined Parking Space Detection Systems (PSDS) as a product of interest to the challenge of parking in the city, including congestion and pollution of the environment. Their OpenCV-based PSDS review involved such methodologies as image processing, object detection, and integration of machine learning. They pointed out that though the camera-based systems are best when dealing with large cities, camera quality and location of sensors are critical elements in determining the accuracy of the systems. Their results were supposed to give researchers a more profound insight into the possibility of using OpenCV to substitute costly arrays of IoT sensors, which in the past used to detect the presence of vehicles by either physical contact or infrared proximity.

Also, researchers such as Shruthi B et al. (2020) have studied multi-storey parking garages, where they suggest the system based on edge detection and coordinate-bound pixel areas that must be used to ascertain occupancy. Their approach combined Tesseract to convert images to text, allowing alphanumerical information in license plates to be extracted to automatically access control and bill, with the number of pixels used to determine occupancy. Kalyani et al. (2023) extended this approach by proposing that many slots could be observed by one camera and the number of pixels calculated to determine they were occupied. It is

ISSN (Online) 2394-2320

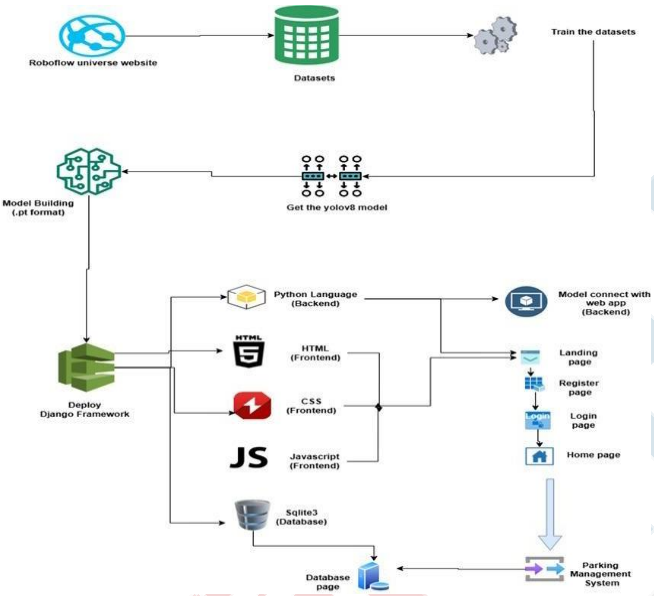
International Journal of Engineering Research in Computer Science and Engineering (IJERCSE)

Volume 13, Issue 6, June 2026

characterized by cost-efficiency because the device can be activated within minutes without disrupting any normal parking activities, and outcomes can be uploaded to a cloud database to provide real-time access to and use mobile applications.

IV. PROPOSED SYSTEM

The Intelligent College Parking Management and Vehicle Monitoring System proposed architecture is a multi-layered architecture that will be responsive in real-time and highly accurate. This is implemented by incorporating the surveillance hardware with some deep learning model and web-based administrative dashboard system architecture to offer a single solution to the campus monitoring system.



4.1. Layer of Data Flow and Processing

Data flow in the system is designed in a series of sequence steps to make sure the raw visual data has been converted to actionable intelligence.

Input Layer: The system retrieves real-time video images by the surveillance cameras at the parking entrance, exit and different areas within the company. These are the main environmental sensors of the cameras.

Pre-processing Layer: OpenCV VideoCapture function is used to extract frames in the live video. Pre-processing refers to the process of resizing the images to the normal 640x640-pixels to suit the input parameters of the YOLOv8 model. The pixel values undergo normalization methods in order to drive them in the range of the range of under zero to over one (i.e.) which makes them easier to converge upon in the inference stage of the model. To enhance the robustness of the model, data augmentation methods are applied during the training process and include rotation and brightness manipulation.

Core Detection Layer (YOLOv8): This layer makes use of the YOLOv8 (You Only Look Once version 8) algorithm in the process of detecting objects. YOLOv8 has been chosen as it is very efficient and precise in real-time performance. The model recognizes cars or motorbikes, creates bounding boxes depicting the position and size of cars in the frame.

Analysis and Logic Layer: After the detection of vehicles, the system matches the coordinates of vehicles and occupancy of parking slots is determined. The system identifies duplications between identified vehicle bounding box and slot borders by dividing the parking lot into fixed blocks or coordinates. A secondary pixel count scan is done to confirm the presence of an occupation; a shift in the pixel density in a slot coordinate is used to notify a shift of the status to occupied.

Output and Deployment Layer: The processed data is pushed to a web-based dashboard that has been developed on a Django framework. This layer deals with the movement logs, parking status logs of vehicles, and user registration information.

4.2. Module Description Functional Module

The system is divided into four main modules, each of which has a different aspect of the monitoring process, to which it is dedicated.

Data Analysis Module: This module is concerned with the first intake and analysis of visual data. It processes statistical summaries and visualization (allowed by libraries such as Matplotlib) to learn about the patterns of parking. It is used to prepare the dataset so that it can be trained, the dataset is labelled and annotated so that the various types of vehicles are represented.

YOLOv8 Module: This is the deep learning component of the system. It caters to high object detection speed. Each frame is processed by the module and matches flames, smoke (when it is used in a fire detection system), or vehicles. It produces bounding boxes and confidence scores that enable the system to monitor the movements in real-time with an accuracy of mAP scores.

Open CV Module: It is involved in the process of the linking between raw video and the detection model. It does frame-by frame processing, thermal image fusion (where feasible), and bounding boxes overlay on the original video stream. It also starts emergency procedures or warnings in case an unwarranted entry is identified.

Deployment Module (Django): The deployment module is developed on the basis of the Django web framework that is a high-level Python-based framework which focuses on security and scalability. The front end is made up of HTML and CSS to generate a professional dashboard that shows the total slots, available and occupied slots of both cars and bikes. It also encompasses the user register and the user log in system; where the sensitive security logs can only be accessed by authorized personnel.

4.3. UML Representation and System Notations

The system design is further discussed using different UML (Unified Modeling Language) drawings, which are the static and dynamic perspectives of the application.

Use case Diagram: This diagram illustrates the top functionalities of the system by depicting interactions between actors (e.g. Administrator, Security Personnel) and the particular use cases such as Detect Vehicle, Monitor Occupancy and Generate Alert.

Class Diagram: This is the diagram that shows the static picture of the system and recognizes the classes like VehicleLog, ParkingStatus, and UserPersonalForm. It determines the properties and behaviour of each of the classes and the interrelationships between the classes.

Activity and Sequence Diagrams: The activity diagram represents how the logic works, also with parallel and branched logic of entry and exit. The sequence diagram is a model of the flow of logic with time illustrating the exchange of messages between the camera interface, the detection engine, and Django database.

ER Diagram: The relational database is based on the Entity-Relationship diagram in which the connections between objects such as Vehicle, ParkingSlot, and User are represented.

V. RESULT AND STUDY

The assessment of the Intelligent College Parking Management system proves the fact that it is effective in automating the process of detection of parking availability and the improvement of campus security. Computational (mAP, FPS) and functional analysis of the dashboard operations are used to measure the performance of the system.

5.1. Computational Metrics Performance

The detection engine of the system was tested on the standard datasets to make sure that the reliability is high. Although the current nighttime systems provided a point of reference, the model based on YOLOv8 was expected to deliver similar accuracy and at the same time, process images in real time.

The processing speed of 45.45 FPS deserves to be noted especially because it is higher than the normal requirements that a parking monitor would have and as such, the system would be able to handle other functions like number plate recognition (OCR) and overspeeding detection at the same time without causing any slowdown. The multi-head neural network method though involving complexity helped in making sure that the system was able to adjust to changes in lighting which is a very important feature to 24hours campus surveillance.

5.2. Dashboard Usability and User Management

The deployment based on Django offers a complete interface to administrators. Dashboard module testing It was ensured that the dashboard module displays real-time parking data successfully.

Parking Layout Analysis: The system is able to analyze an image of blank ground (with the help of generative AI models (in this case Gemini-2.5-flash)) and approximate the real placement of car slots (2.5mx5m) and bike slots (1.2mx2.5m), including the consideration of driveway spacing.

Entry and Exit Logic: The Entry Camera module is used to ensure that the vehicles can only enter when there are slots. When there is no vacant space in the car and bike parks, the system automatically sends a parking Full message and diverts the drivers to other places.

Vehicle Logging: The system keeps an active record of all the entries and exit. As an example, the system will document the entry of allowed +1 car(s) and change the database. When leaving, the system will empty the allocated slot and is able to generate billing according to length of stay which enhances the management of revenue in the institution.

Security Monitoring: The administrative interface shows the security events and movement history. It issues notifications about the offenses like over speeding or parking unlawfully in restricted areas hence improving campus security.

5.3. Environmental and Resource Analysis

The feasibility study established that the system is intended to be efficient although there are some limitations that need to be addressed. Extreme weather conditions like fog, rain or heavy glare that may obscure the car features may negatively affect performance. This is taken care of by the system through the use of point-based detection where full bounding boxes are not available in an exact determination. Concerning hardware, one would need at least 4 GB of RAM and an Intel-i3 processor to do the simplest tasks although running it on a high resource server with a strong GPUs is advisable to achieve the best results in training the deep learning layers. It has a software environment based on the Anaconda and Python systems that Cater to the requirements of the various packages to ensure that every package version has the corresponding set of dependencies to run properly through the Conda environment manager.

VI. FUTURE ENHANCEMENT

The opportunities of the Intelligent College Parking Management system in the future can be based on the advanced identification and cloud technologies. One of the major improvements is the high-accuracy AI-based license plate recognition (LPR) and the connection with mobile applications. This would allow the students and staff to look up real-time availability of parking on their smartphones even before coming to the campus. Moreover, the system may have automated entry and exit via a mobile application and have pre-reserved parking slots. This would not only enhance the system easy to use but also enable the institution to install an advanced permit system whereby authorized vehicles are automatically recognized without the physical use of stickers or guard at the gate.

The second significant improvement is that the system can be scaled with the help of IoT sensors and predictive analytics on the cloud. Although the existing vision-based system is affordable, its integration with a multi-campus cloud infrastructure would enable the management to monitor several parking lots all through one central command center. The system would be able to predict the peak occupancy times using the predictive analytics on the historical vehicle logs, and would recommend alternative schedules or parking zones to administrators. This would facilitate intelligent decision making to the future campus infrastructure planning and offer sophisticated security surveillance that detects abnormal movement patterns over a long period. This scalability will guarantee that the system is an all- encompassing and future-proof system in the current smart campus settings.

VII. CONCLUSION

The Intelligent College Parking Management and Vehicle Monitoring System based on the OpenCV and real-time computer vision technology is an effective, automated answer to the age old problem of parking in the college. Through the strength of deep learning and real-time video processing, the system will help to minimize the necessity of the human factor, the value of overall traffic congestion, and boost the work of the institutions. The combination of multiple computational modules, such as the fast YOLOv8 detection engine, and the safe Django web dashboard, forms a solid framework that has a functional and technical integrity.

The outcomes of the implementation confirm the fact that the system is able to monitor the vehicles correctly and control the use of space even in crowded and complicated situations. The capacity to differentiate between car and bike parking, identify license plates, and create automatic logs will grant administrators a better understanding of the dynamics of vehicles on the campus than ever seen. The presented project proves that vision-based technologies are not only a cheaper alternative to traditional IoT sensor arrays but also can offer a greater degree of security and data granularity. All in all, this smart solution will create a smarter, safer, and better structured college life, which will serve as the prototype of building smart campuses.

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