Vehicle Parking Area Monitoring and Management System using Computer Vision

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ABSTRACT

The increasing number of vehicles plying thoroughfares requires consequently expanding parking areas in major destinations. In a school setting, where classrooms and academic facilities are an utmost concern, the provision and management of parking areas take a back seat. This study attempts to develop a vehicle parking monitoring and management system to provide convenience and accessibility to stakeholders of a target university in the Philippines. It seeks to optimize the utilization of parking spaces by providing information to vehicle owners on available parking slots, deliver data insights to the school administration for better management and planning, and contribute to the reduction of carbon emissions from cars roaming around looking for an available parking slot. A video camera or a recorded video clip of the parking area can be used as input into the Python programming language paired with OpenCV, a library of computer vision functions. After which, vehicle detection and tracking is performed using YOLOv8. The dedicated web application for management and monitoring is developed using HTML, CSS, and JavaScript complemented by Node.js, Bootstrap, and MongoDB. The study followed the Agile software development lifecycle methodology. The developed system proved to be successful in determining whether specific parking slots are occupied or not, therefore can guide users where to park their vehicles. Illegally parked cars can also be detected by the system. Furthermore, hourly, weekly, and monthly parking data can be generated for better parking management and planning.

Keywords: vehicle parking, computer vision. OpenCV, yolov8

INTRODUCTION

Based on the latest economic indicators, historic data and forecasts released by CEIC Data (2024), the Philippines had a total of 4,951,662 registered vehicles in 2021. For June (2024), car sales were reported at 39,088, two percent higher than the previous month. The continuous growth in the number of vehicles contributes to traffic congestion not only on metropolitan roads but also in parking areas. Vehicle parking emerges as a pivotal component in city infrastructure, influencing daily life by ensuring seamless mobility and access, whether navigating through busy city streets or seeking a convenient spot near institutions such as schools (Litman, 2023). The need for efficient parking management strategies is becoming increasingly urgent. As urban areas expand, the implementation of effective and efficient parking solutions requires equal consideration to promote smooth traffic flow and enhance overall city functionality.

Colleges and universities are experiencing a surge of students and faculty members who drive their cars to work each day. With these observations, the concerns about the sufficiency of parking spaces on school campuses have been raised and thus alarming the academic community (Ezarik, 2022). The target university in Silang, Cavite, located 50 kilometers (about 31.07 miles) south of Manila, is among many educational institutions experiencing a significant increase in the volume of traffic within its vicinity. The traffic surge on campus is regularly observed during class hours on regular school days, enrollment periods, university events, and during scheduled church services. It places a burden on the available parking resources resulting in traffic congestion and inconveniences that ripple across the academic community (R. Pesigan, Public Safety Department officer, personal communication, November 9, 2023). There are many available parking areas on campus, such as the central car park, road-side parking near the university library and park, the administration building areas, and the different parking areas for the colleges and other establishments. The largest of which is near the main gate, around 600 meters (about seven minutes' walk) from the college classrooms and offices.

When parking a vehicle, the tendency of a stakeholder is to park nearest to the intended destination. During school hours, for example, the parking areas nearest to the classrooms are filled-up first followed by the next close by locations. When another vehicle comes to park, the nearest parking area is scanned first then moves farther to the next parking area until a vacancy is found. Since there are no existing parking monitoring systems on campus, every minute spent roaming around means irreplaceable time and precious resources are spent unproductively, which also degrades the environment due to air pollution from vehicle emissions. Moreover, there are no systematic and comprehensive sources of data that can provide guidance into the decision-making process and considerations for future development of campus parking areas.

This study sought to develop a vehicle parking area monitoring and management system. Specifically, the system aims to provide convenience and efficiency by assisting drivers in locating available parking spaces, contribute to the management of parking areas without the need for additional workforce, and generate statistical information regarding the utilization of parking areas.

The Agile methodology was utilized in the project. The framework facilitated quick incorporation of changes if there were insights or adjustments needed during the development process. The iterative nature of a sprint allowed for flexibility and adaptability to changing requirements (Al-Saqqa, et al., 2020). Using computer vision technologies, such as OpenCV and YOLOv8, parking slots can be determined to be occupied or vacant. The information is then sent to a management application developed using Node.js, Bootstrap, and MongoDB that provides real-time parking information among other useful statistics.

LITERATURE REVIEW

There are many available technologies that can be implemented in managing parking areas. One approach is by using hardware sensors connected to a microcontroller to detect a parked vehicle.

A study was conducted by researchers from several universities in Indonesia. It utilized an experimental approach in exploring the utilization of a Radio-Frequency Identification reader integrated to a microcontroller to create a subscription-based parking system for a university campus. The researchers assembled an RFID block reader hardware using microcontroller parts, tools, and instruments. Then, a software was coded to utilize the hardware. After undergoing testing and analysis of the results, the study showed that the automatic subscription-based parking worked well and performed faster (Hidayat et al, 2021).

In the Universiti Malaysia Perlis, another study was conducted to address the issue of parking scarcity in the campus. The project utilized a Raspberry Pi microcontroller augmented with Closed-Circuit Television (CCTV) camera and ultrasonic sensors. These devices are strategically deployed in parking spaces to detect vehicles. Red and green LEDs are utilized to inform users regarding parking availability. After gathering, the data are stored in cloud-hosted Firebase database where it is processed and analyzed. Additionally, real-time parking updates are also accessible to a dedicated mobile application. The system provided convenience and up-to-date parking information to the users (Yee, 2020).

Several similar studies were also conducted in the Philippines. Instead of using Raspberry Pi, this study by Ferol et al. (2020) explored Wemos D1 Mini (narrowband Internet-of-Things capable) Wi-Fi-enabled microcontroller paired with ultrasonic sensors to determine parking slot status. The gathered data is stored in Firebase with the corresponding web application developed using MIT App Inventor. LED indicators were also utilized to declare the parking slot status. A distinction in the software implementation of this study is the capability for users to reserve a parking slot. A maximum of 10 minutes can be allotted for a driver to proceed to the reserved parking area. During this time, the slot will be considered taken. The developed system proved to be effective in a parking application and can provide users with information to locate and reserve parking spaces.

Another study in the Philippines by Tambong et al. (2021) utilized Arduino Mega with connected ultrasonic sensors to detect obstacles within a programmed range. An obstacle can be interpreted as a parked vehicle. Wi-Fi connections link the hardware to an online database which is then accessible to an android application. After multiple trials, the results proved to be accurate, functional, reliable, and usable.

The second approach for managing parking is to use computer vision. According to IBM (2021), it is a field of artificial intelligence that extracts information from digital images and videos using computer systems. The image-based approach utilizes large datasets as training inputs to machine learning algorithms to recognize and distinguish objects (Bhatt et al., 2021). This is an emerging technology and the number of parking management systems utilizing the computer vision approach is increasing.

In a study conducted in India (Singh and Khan, 2019), a system is proposed to recognize occupied and free parking slots through the utilization of the Prewitt Edge Algorithm (PEA).

The PEA detects edges by analyzing abrupt changes in pixel intensity in both horizontal and vertical directions. The system can recognize vehicle parking states such as partially, fully, or wrongly parked. It is also capable of distinguishing vehicles from other obstacles that could be situated in the parking slot which may result to false detections when using hardware sensors. For the system to function, the coordinates and dimensions for each parking slot must be declared first. The PEA will then be utilized to track changes in the declared areas. If there are changes, the aspect ratio of detected changes is examined to determine whether it is really a vehicle or an obstacle. The movement of the vehicle whether parking or moving out of the area is also considered. The results showed that the system can efficiently determine if a vehicle is parked in a spot or not. The system is developed using the Python programming language and the OpenCV library. A monitoring application is not included in the study.

Conducted in 2022 (An et al.) in China, another study proposed to solve the parking area problem using a deep learning methodology. In this approach, the researchers utilized an image dataset made up of 7,533 different vehicle types which are observed under various conditions. From the entire dataset, a group of 6,387 were used for training, while the remaining 1,146 were used for testing. Each of the pictures were labelled accordingly using the LabelImg image annotation tool. The process begins by ingesting the video into OpenCV followed by determining the parking spaces. The coordinates will have to be declared, but instead of hard coding it into the system, it is automatically determined using a recorded instance where all the parking slots are occupied. The identified parking slots are then virtually numbered for drivers to easily pinpoint them. After which, the parking slot is evaluated to be either occupied or available. Multiple points located from within the coordinates of each identified slot are randomly plotted. Each random point is evaluated using density clustering and the indirect Monte Carlo algorithm to determine if a portion of the vehicle overlaps the random point. The collective result of random point overlaps determines the probability of a slot being occupied or available. The overall detection results of the study proved efficient as more movement of vehicles is detected.

The study by Sharma (2022) in Canada focused on the development and evaluation of a smart parking system leveraging computer vision and machine learning techniques for accurate parking spot detection. Two prominent machine learning models, Faster-RCNN and Mask-RCNN, were selected for experimentation. The study involved the utilization of a recognized parking lot dataset and creation of a customized dataset tailored to the study's specific needs. The images were annotated using VGG Image Annotator while Dynamic Histogram Equalization was employed to enhance image contrast and visibility. The study also developed an Android mobile application that provided real-time information on parking space availability and enabled parking booking. The study resulted in a scalable, cost-effective, and higher parking spot detection accuracy application.

Another study's (Thakur et al., 2023) purpose is to develop a less expensive substitute for sensor-based parking monitors. It utilized a convolutional neural network approach to recognize parking spots in a parking area and determine whether it is vacant or occupied. The study implemented Resnet50 combined with support vector machine and VGG16 combined with OpenCV functionalities achieving 98.9% and 93.4% accuracy, respectively. The PKLot dataset was used to train and test the model. It is made up of 12,419 images under different climate conditions in Brazil. From the images, 695,899 individual parking slots were extracted and manually labelled as vacant or occupied. It is noted, however, that the dataset lacks night shots of the parking lots (Almeida et al., 2015).

Published in 2024, Neupane et al. ventured on a study to solve parking related issues in South Korea. Due to the unavailability on certain occasions, parking areas designated for persons with disabilities are being used by vehicles not bearing disability badges. The badges are oval or circle, color-coded, marked with a disability logo, and contain a 4-digit number that is linked to its corresponding license plate number. Current plate numbers in the area come in five formats with varied foreground and background colors, and sizes. The diverse formats of the objects to be detected incorporated with the changing climate and lighting conditions are the presented challenges in developing the system. To solve this problem, the authors proposed a deep learning model that detects the vehicle, its license plate, and the presence of a disability badge. The system is developed using YOLOv7 using a custom dataset of 30,000 images obtained from public parking lots, government websites and online databases. The images are labelled using makesense.ai and split into 90% training and 10% testing sets. The mean average precision of the model is recorded at 92.16%. After the system detects and determines the vehicle information, the values are sent to a central server for validation of vehicle privileges.

Using radio frequency and ultrasonic sensors connected to microcontrollers to detect a parked vehicle has been established and proven to be effective in providing real-time parking area information. This implementation allows for a wide choice of microcontrollers ranging from Raspberry Pi, Arduino, narrowband Internet-of-Things devices, among others. The result of several studies (Hidayat et al., 2021; Ferol et al., 2020; Tambong et al., 2021) demonstrated the capability of the technology to gather localized information that can be stored, managed, and utilized to provide useful information to a vehicle parking monitoring system. Parking slot LED indicators that signal whether a parking spot is occupied or available even from a distance is a very user-friendly approach. It proved effective even without a dedicated application. However, several drawbacks have also been identified. Installing sensors for every parking slot will be costly. The outright expense for a microcontroller kit with sensor ranges from $30.00 to $70.00 depending on chosen components. The cabling for power source and signal transfer will also have to be planned properly to be aesthetic, sufficient, and secure. And when everything has been installed, maintenance cost and complexity will be another factor to investigate. Troubleshooting for either a single or multiple errors in the entire expanse of the parking area will require expertise and perseverance. False positive detections can also occur due to obstructed, misaligned, or soiled sensors. Since most parking areas are exposed to an open environment, extreme temperatures and pollution, the sensors will require frequent checking and calibration. As far as the mentioned drawbacks are concerned, the implementation of using sensors and microcontrollers can be feasible for a small and control-intensive area, but as the parking area capacity increases, the more costly and rigorous the implementation will become.

The computer vision approach aims to introduce a more reliable and scalable method for determining parking slot state (Singh and Khan, 2019; An et al., 2022; Sharma, 2022; Thakur et al., 2023; Neupane et al., 2024). Unlike with the previous technology of assigning one sensor for every parking slot, a camera connected to a computer vision system can detect as many cars as it can fit in a frame. Adding more cameras can drastically increase the detection capacity. Chances of obstructions are also reduced since the camera is placed in an elevated position. Calibration and declaration of slot boundaries will still be required for some implementations (Singh and Khan, 2019; Sharma, 2022), but the effort is not as intricate as the previously mentioned technology. The studies of An et al., 2022 and Thakur et al., 2023, however, eliminate the task of defining individual parking slots as they are automatically determined by the system. There are also options to use cameras with zooming and panning capabilities that are useful for quick calibrations. Outdoor cameras are also available and can withstand more than the usual weather conditions. Camera procurement and maintenance costs will also be limited as existing surveillance cameras can be utilized in the process. System software can also be installed on existing servers instead of buying a new one to minimize costs.

With the literature stating varied approaches in monitoring parking areas, the computer vision approach is deemed to be the more appropriate technology considering the environment of the target university

METHODS

The area examined in this study, despite the many parking areas in the target university, is the central car park. It is the largest of the parking areas situated closest to the library and most of the college classrooms. It is paved with coarse gravel and rock fragments making it difficult to put a delineating line to separate one slot from the next. However, there are concrete parking stop blocks to indicate the orientation or placement of vehicles. These also determine the number of cars that can park in each row. It has the capacity to park 75 light, four-wheeled vehicles. The motorcycle parking area is not considered in this study because motorcycles are not having as many parking difficulties as four-wheeled vehicles as of the time of study. Due to time limitations, we, the researchers, decided that only ten parking slots belonging to two different parking rows will be observed. The goal being sought to determine if a parking spot is occupied or available remains the same and the discovered solutions will be carried over to the unconsidered spots once deemed necessary.

The approval to conduct the study and the initial data used for the background study were sought from the Public Safety Department (PSD) since they are in-charge of the operation of the university's parking areas. After observing the target parking area and determining the specific parking spots for the study, we sought permission from the Data Protection Officer (DPO) regarding our planned video recording activity. The approval was granted, and we were also advised to post a privacy notice visible to all passersby on the week of the scheduled activity. The privacy notice includes all the details of the planned data gathering such as the date and time, means, technology, as well as the contact details in case there are privacy concerns. This is necessary to assure the public that the collected data will be anonymized, and in accordance with Philippine laws. In-person interviews and written requests were the preferred means of communication when seeking approvals.

To capture the best possible view of the parking area, we mounted a mobile phone equipped with a 12-megapixel camera to a three-meter pole. A packaging tape was used to secure the phone to the pole. Several video clips with varying durations ranging from 15 to 30 minutes, recorded in the morning and afternoon where there is ample vehicle movement, differing lighting or illumination, and other conditions were recorded in mp4 format. To further ensure substantial vehicle movement is documented, a fellow was requested to drive her car from one parking slot to another. Although recorded videos of vehicle movements are used during the study, actual live video feeds taken by cameras situated in parking lots will be utilized in the implementation.

After gathering, the video clips were trimmed down by selecting only the clips with frequently moving vehicles. It was then fed into the Python programming language with OpenCV, a library of computer vision functions, for processing. Once the video clips are loaded into the system, it can now be integrated to machine learning models and algorithms. Initially, we intended to train and test a model from our gathered video clips but as the study progressed, our focus shifted to established models. As a pre-trained computer vision model, YOLOv8 can detect objects, image segmentation and image classification, among other AI tasks. Although it can be used to create a new model using a custom dataset, we opted to try how it will perform in our local setting without fine-tuning or adjustments. Since the problem we are trying to solve focuses on detection of vehicles and is not exposed to a lot of risks, we decided to use and evaluate the pre-trained vehicle detection model in its default configuration. This step is crucial because it will save a lot of time, resources and effort as compared to training, testing, and fine tuning a new vehicle detection system. Once the system can detect the presence of vehicles in the video, coordinates of the upper left and lower right corners of each parking slots are then designated so that only the vehicles detected within in the coordinates are counted as parked. Coordinates of the road where parking is prohibited have also been plotted so that illegally parked cars can be detected by the system. A time threshold is assigned to differentiate a passing vehicle from an illegally parked vehicle. The determined state of the parking slots and the road (for illegally parked vehicles) is stored in MongoDB.

The management and monitoring web application was developed using HTML, CSS, and JavaScript with the aid of the Node.js and Bootstrap frameworks. Microsoft Visual Studio Code was utilized for coding the system. The study followed the Agile software development lifecycle methodology.

RESULTS AND DISCUSSION

The configuration that we implemented achieved a precision of 74%, a recall of 63.4%, and an mPA50-95 of 52.9%. It does not have outstanding scores compared to contemporary studies that utilize custom datasets and fine tuning but was able to perform the tasks at hand without much effort. After rigorous testing using our gathered videos on site, we observed that YOLOv8 performed excellently in detecting vehicles. Once a vehicle is detected in a video feed, a bounding box with an accompanying confidence detection score is provided. Factors affecting changes in confidence levels include video quality, angle of the vehicle and partially obscured vehicle or when the vehicle is not fully included in the frame. One of the very few instances where a false negative detection occurred is when less than half of a car is displayed in the video frame which resulted in identifying it as a truck. The misidentification, however, did not affect the outcome of the system as the parking spot is still considered occupied. Vehicles parked beyond 20 meters from the camera will also have lower confidence levels. Based on these observations, the placement of the camera holds a key role in the accuracy of the parking monitoring system. The target parking spots need to be fully contained in the video frame to ensure higher confidence detection scores. Furthermore, if there are multiple rows of parking, there are chances that the rows nearer to the camera can partially block the rows behind it. Therefore, with that premise, the camera should be placed in an elevated position to achieve a full view of each row of parking spaces. If, even after raising the camera position, a row of parking still obscures another, it is deemed necessary to add another camera that will monitor the previously obscured row. The two cameras will each then be assigned different parking slot coordinates that will act as barriers to prevent misreporting. Even if the same vehicle is detected on both cameras, it will only be reported to be parked to the camera with the occupied parking slot coordinates.

Parking slots are arranged differently, such as parallel, diagonal, or perpendicular to the curb. This, and the camera position, can induce a possibility that the coordinates of parking slots will partially overlap with one another. To promote proper counting even with partially overlapped coordinates, there should be a single identifying point in the vehicle that can be designated to be the basis of determination so that it will only occupy one parking slot. Fully overlapping or very narrow differences in the plotted coordinates will result in possible inaccuracies in detection.

The detection mechanism stores the output to a database which is accessed by a web application. The web application can be accessed by the university's students, faculty, and staff of the university without the need to login to the system, if they are connected to the campus intranet. Any modern browser running from a computing device with a substantial screen size can be used to view parking information. The application's main page displays a web carousel of the different parking areas for easy navigation. Each carousel slide displays the parking area name, a map snapshot of its location and the corresponding count of the available parking spots. A detailed view will be displayed after tapping a link which will provide a visual representation of the parking area. A green car icon represents an available parking spot while a red car icon represents an occupied spot. There is no reservation capability in the system, therefore it is on a first-to-come, first-to-park basis.

In the event where vehicles are improperly parked and cannot be viewed fully by the parking system, a user reporting feature is incorporated into the web application so that such incidents, among others, can be directed to the Public Safety Department for proper rectification and management. Users can submit reports via the Contact Us link in the menu. To validate users, the system sends a one-time password to a user-provided mobile number or email address. Information such as name and contact information of the user, data and time of the report, and the report details are viewable only to the PSD. The PSD, being the overseeing authority, needs to login into the system to be able to perform administrative functions. Reports are then archived after being settled.

The Statistics page provides insight into the parking area utilization. It presents hourly, weekly, and monthly column charts for each area to inform users about less busy hours or schedules where parking is at peak. For the PSD, this information can be used for planning and development purposes such as for proper and sufficient personnel deployment based on which area needed them most. Expansion or improvement of parking areas can also be based on the generated insight for a more precise use of financial resources.

To maximize awareness, the terms of use for the application and the parking rules and regulations are also posted on the Rules and Regulations portion of the website. It presents the expectations and requirements needed for maintaining a safe, organized, and efficient parking environment and to ensure smooth flow of traffic and parking on campus. A set of frequently asked questions are also presented in this section.

CONCLUSION, IMPLICATION, SUGGESTION, AND LIMITATIONS

In the end, this study resonates with the papers written by Singh and Khan (2019), An et al. (2022), Sharma (2022), Thakur et al. (2023), and Neupane et al. (2024) which leaned towards using computer vision in monitoring parking areas. Using cameras that can detect multiple parking spot instances at the same time implies to be less costly in acquisition and operations and are more scalable. The locally developed system employed OpenCV and the default configuration of the pre-trained YOLOv8 model proved to be capable and effective in determining parking spots availability. Furthermore, by utilizing the default configuration of a pre-trained model, substantial time can be saved in developing applications contributing to faster software evolution and fulfillment of business requirements. The procedure, however, will require proper camera placement because it holds a critical role in the system's effectiveness. Vehicles that are not fully visible in a camera frame can result in incorrect detection and counting. Although vehicles can still be detected, it is recommended that vehicles' distance from the camera should not exceed 20 meters to reduce possible image noise and blur. Based on these results, the system is deemed an appropriate solution for determining parking states in the target university. For larger implementations outside of the university, proper evaluation should be considered to determine feasibility and applicability of using a model with default configuration. For future implementations of the system, we recommend creating a dedicated mobile application for better user experience. Disallowing the intranet-only connection while still upholding privacy and security can also be considered. And lastly, adding a reservation capability as well as pay-as-you-park feature can be studied to determine its viability.

REFERENCES

Almeida, P. R. L. de, Oliveira, L. S., Britto, A. S., Silva, E. J., & Koerich, A. L. (2015). PKLot – A robust dataset for parking lot classification. *Expert Systems with Applications*, *42*(11), 4937–4949. https://doi.org/10.1016/j.eswa.2015.02.009

Alsaqqa, S., Sawalha, S., & Abdel-Nabi, H. (2020). Agile software development: Methodologies and trends. *International Journal of Interactive Mobile Technologies (iJIM)*, *14*(11), 246–270. https://doi.org/10.3991/ijim.v14i11.13269

An, Q., Wang, H., & Chen, X. (2022). EPSDNET: Efficient campus parking space detection via convolutional neural networks and vehicle image recognition for intelligent Human–Computer interactions. *Sensors, 22*(24), 9835. https://doi.org/10.3390/s22249835

Bhatt, D., Patel, C., Talsania, H., Patel, J., Vaghela, R., Pandya, S., Modi, K., & Ghayvat, H. (2021). CNN Variants for Computer Vision: History, Architecture, Application, Challenges and Future Scope. *Electronics*, *10*(20), 2470. https://doi.org/10.3390/electronics10202470

CEIC Data (2021). Philippines | Economic indicators, historic data and forecasts | CEIC. Retrieved from https://www.ceicdata.com/en/country/philippines.

Ezarik, M. (2022). Campus parking problems common yet not universal (infographic). Inside Higher Ed | Higher Education News, Events and Jobs. Retrieved from https://www.insidehighered.com/news/2022/12/14/campus-parking-problems-common-yet-not-universal-infographic

Ferol, J. C., Enriquez, C. J. P., Morano, S. M. B., & Nisay, H. F. (2020). Android based smart parking system in preparation to narrowband internet-of–things technology. *Linang*, *2*(1), 43–51. Retrieved from https://www.letranbataan.edu.ph/Files/Research/Linang2019-2020/V1/Article%205.pdf

Hidayat, R., Rushendra, Afiyah, S., Sufyani, R., & Adani, F. (2021). Development of Radio Frequency Identification (RFID) in the Campus Parking System based on Microcontroller. *Journal of Physics: Conference Series*, *1783*(1), 012022. https://doi.org/10.1088/1742-6596/1783/1/012022

IBM. (2021, July 27). What is Computer Vision? | IBM. https://www.ibm.com/topics/computer-vision

Litman, T. A. (2023). Parking Management Strategies, Evaluation and Planning. *Victoria Transport Policy Institute*. Retrieved from https://www.vtpi.org/park_man.pdf.

Neupane, D., Bhattarai, A., Aryal, S., Bouadjenek, M. R., Seok, U., & Seok, J. (2024). Shine: A deep learning-based accessible parking management system. *Expert Systems with Applications*, *238*, 122205. https://doi.org/10.1016/j.eswa.2023.122205

Sharma, A. (2022). Towards the development of a cost-effective Image-Sensing-Smart-Parking Systems (ISenSmaP). *Electronic Thesis and Dissertation Repository*. 8873. Retrieved from https://ir.lib.uwo.ca/etd/8873

Tambong, A. C. O., Aromin, M. E., Fabian, T. A. M., & Vergara, N. D. P. (2021). LPU PARK'n GO: An android application for realtime parking availability in Lyceum of the Philippines University Cavite. *International Journal of Computer Science and Information Technology Research*, 9(1), 117–122.

Thakur, N., Bhattacharjee, E., Jain, R., Acharya, B., & Hu, Y.-C. (2023). Deep learning-based parking occupancy detection framework using ResNet and VGG-16. *Multimedia Tools and Applications*, *83*, 1–24. https://doi.org/10.1007/s11042-023-15654-w

Yee, O. C., Yaakob, N., Elshaikh, M., & Azahar, F. (2020). A cloud-based automated parking system for smart campus. *IOP Conference Series*, 767, 012049. https://doi.org/10.1088/1757-899x/767/1/012049