SmartSpectorAI: Roadside Parking Warning System for Congestion Prevention in Yogyakarta City

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Abstract. Traffic congestion has been a major problem in big cities, including Yogyakarta, with negative impacts including time, economic, and psychological losses. Based on data from the Yogyakarta Special Region Transportation Agency and Yogyakarta City Transportation Agency, analysis of congestion level data, and field observations, it was found that one of the main causes of congestion on the most congested roads in Yogyakarta City is vehicles parked on the side of the road. The proposed solution involves roadside parking detection and warning using surveillance cameras integrated with Artificial Intelligence (AI). The proposed system involves vehicle detection with pre-trained deep learning models, parking detection algorithms with Intersection over Union (IoU) tracking, and alerts that are forwarded to motorists as well as authorities such as the Transportation Department and local traffic police. The Yogyakarta CCTV dataset is used to test parking detection using various models, such as YOLOv5-medium, YOLOv5-large, YOLOv7-tiny, and Haar Cascade. The model evaluation shows that YOLOv5-large provides the highest accuracy of 86.1% with a processing speed of 5.5 Frames Per Second (FPS) to perform parking detection. With this proposed system, this research can contribute to solving congestion problems and improving traffic conditions in Yogyakarta City.

INTRODUCTION

With the number of vehicles and population increasing over time, traffic congestion has become a serious problem in major cities in Indonesia and around the world. Yogyakarta is one of the cities facing this problem. Based on data from the Yogyakarta Special Region (DIY) Provincial Transportation Office, despite a decrease in 2020 and 2021 due to the Enforcement of Restrictions on Community Activities (PPKM), the performance of road sections in Yogyakarta City was initially at a VC index [1] of 0.759 in 2019 [2]. This figure indicates that the road service level is at level D or the traffic flow is approaching an unstable level [3]. The increase occurred again after the pandemic in 2022, where this problem was also supported by a periodic increase of about Y in the number of vehicles each year, where in 2022, this number touched 3,622,220 units [2]. This shows that the intensity of congestion in Yogyakarta City has increased in the last period of time.

The high intensity of congestion also has an impact on society and the environment. The impacts of congestion include increased travel time resulting in delays, increased fuel consumption which impacts air pollution, and increased psychological stress for road users [4]. In addition, congestion can also reduce community productivity and increase economic costs such as transportation costs and time losses [5]. Based on literature studies, research conducted by [6] shows that the value of congestion losses in Yogyakarta City caused by vehicle operating costs on Magelang Street reaches Rp.7,658,819,837.26 (approximately USD$480.477,59, 23 October 2023 currency) per year. The congestion analysis at Pasar Sentul intersection shows poor performance with congestion costs reaching IDR 3,722,627 (approximately USD$233,54, 23 October 2023 currency) per hour based on research [7]. Therefore, there is a high urgency to prevent congestion.

In formulating a preventive solution to the city's congestion problem, a comprehensive understanding of the causes of congestion is required. To find the specific causes of congestion, we conducted an analysis to identify highway sections in the city that are classified as having the highest congestion severity. Based on the survey results and the traffic performance update study of the Jogja City Transportation Agency, the roads that require special attention in solving the congestion problem include Gejayan Street, Pierre Tendean Street, Adisucipto Street (west to east direction), Suroto Street (north to south direction), and Taman Siswa Street. Supporting data from the Yogyakarta Special Region Transportation Agency shows that there is an annual congestion trend on Utara Simpang Wojo Street, Mataram Street, Wates (in front of Gamping Fruit Market) Street, and AM Sangaji Street (in front of Gurami Bangjo).

Next, observations were made to find the concrete causes of congestion on these road sections. To do this, we used data obtained from the Google Maps traffic feature in the map details section of this application, which we accessed on August 20, 2023. Through this feature, data was obtained in the form of smoothness class information from 6 am to 10 pm on various road sections. We interpreted the road details on the map, where green is interpreted as class 1 (unimpeded), orange as class 2 (moderate congestion), red as class 3 (severe congestion), and dark red as class 4 (severe congestion or stoppage).

This data is used for further analysis of the hours and sections of road that often experience congestion. For each road, road segments that have the most significant fluctuations in congestion levels in the data were selected, namely Terban Street (UGM Roundabout - Mirota C. Simanjuntak Intersection), Adisucipto Street East UIN Sunan Kalijaga T-junction, Wates Street in front of Gamping Main Fruit Market and Gejayan Street South Demangan Market. Congestion level data for both forward and backward lanes for each selected road segment were aggregated into weekday and holiday classes to see the pattern of congestion levels through the visualization in Figure 1. The detailed location of these roads on the map shown in Figure 2.

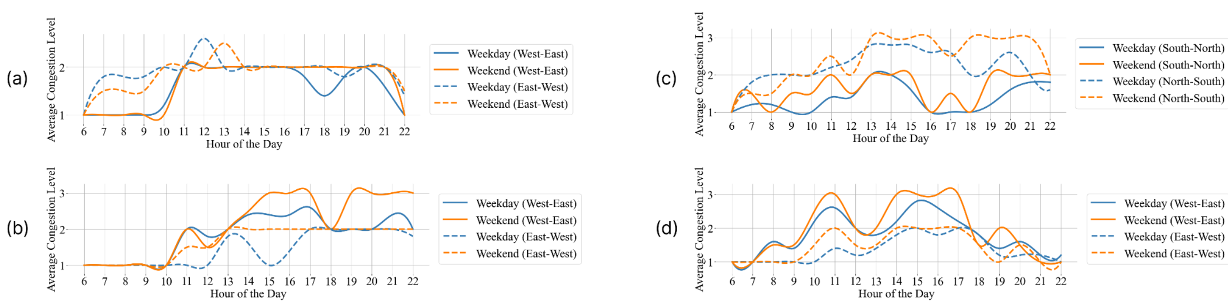

FIGURE 1. Congestion Level per Hour: Weekdays vs. Weekends (a) Terban Street (UGM Roundabout - Mirota C. Simanjuntak Intersection), (b) Adisucipto Street East of UIN Sunan Kalijaga T-junction, (c) Gejayan Street South of Demangan Market and (d) Wates Street in front of Gamping Main Fruit Market.

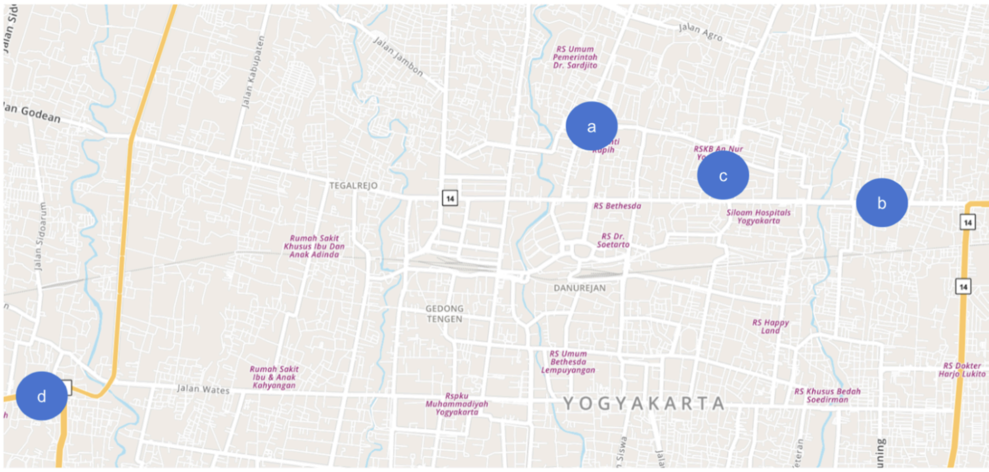

FIGURE 2. Location of congestion points (a) Terban Street (UGM Roundabout - Mirota C. Simanjuntak Intersection), (b) Adisucipto Street East of UIN Sunan Kalijaga T-junction, (c) Gejayan Street South of Demangan Market and (d) Wates Street in front of Gamping Main Fruit Market.

In addition, observations made on-site and through the ATCS of Yogyakarta City provide insight that there is intense community activity during these hours, especially in the Demangan Market area located on Gejayan Street, the highest congested road in Yogyakarta City in 2022. We found that the congestion hours identified are the operating hours of the market as well as the shops located in the area. The higher intensity of on-street parking on other streets is also during the operating hours of the markets and shops on the street.

With this analysis and observation, we found that the main cause of congestion on these roads is the use of the roadside for parking. This is in line with the research conducted in [8] that low public awareness regarding the utilization of traffic facilities causes transportation problems in the Yogyakarta City area. Research by [3] and [9] also clarified the effects of roadside vehicle stops on reducing road capacity and increasing VC ratios. These regulations prohibit actions that result in disruption of the road function on the road useful space which includes the road body, roadside channels and safety thresholds, with disruption defined as reduced road capacity and traffic speed.

Thus, to solve the existing congestion problem, a solution is needed that can restore the capacity of the road so that it can accommodate the volume of vehicles optimally. One of the measures that can be taken is to prohibit the use of roadways as parking lots. In addition to conventional methods such as stricter enforcement of parking regulations, there is also advanced technology in the form of parking detection systems. Some countries have adopted this technology by using devices such as infrared or CCTV in the detection system. Unfortunately, this method has not been widely implemented in Yogyakarta City or Indonesia as a whole.

The opportunity to implement this solution in the city of Yogyakarta and its surrounding areas is supported by an interview with the Head of the Transportation Technology Section, Taufan Abdi Soelaiman, who indicated that there is a seriousness in addressing congestion problems in the Yogyakarta area. In addition, there are also plans from the Yogyakarta Provincial Transportation Office to implement "Smart Traffic Light" technology which also has the potential to meet demand in Indonesia, especially in market areas that are prone to congestion due to vehicles parked on the road.

Therefore, in the context of this research, we propose a system concept designed to monitor and provide alerts when a vehicle is detected parked on the road, especially on the roadside. Our proposed approach involves the utilization of YOLO (You Only Look Once) technology to perform visual detection using street CCTV images. The collected information on the parking situation will be forwarded to the Transportation Department, local traffic police, and also potentially generate live alerts that can be relayed to motorists.

LITERATURE REVIEW

Various methods have been used to detect and localize parked vehicles in different scenarios. Lou et al. implements wireless vehicle detectors (WVDs) in smart parking management systems (SPMS) by addressing the limitations of magnetometer-based vehicle detection algorithms (MB-VDA) [10]. To achieve this, the study proposed an innovative IoT-Driven vehicle detection method that combines data from Ultra-Wideband (UWB) channels with magnetic signals. The method utilized the length of propagation paths and channel impulse response (CIR) signatures obtained from UWB modules, supplementing magnetic sensor data. Importantly, the UWB-based detection algorithm was selectively activated, saving energy, and improving efficiency, as compared to constant UWB activation. The proposed approach was rigorously tested in a commercial parking lot, and the results showcased an impressive detection accuracy of 98.81% under various conditions, particularly when the magnetic sensor operated at a 1 Hz sampling rate. Paidi et al. in [11] employed thermal cameras to collect video data under varying environmental conditions, from which frames were extracted to create a dataset. Since pre-labelled thermal images were not available, manual labeling of frames was carried out. Deep learning algorithms, including YOLO, YOLO-conv, GoogleNet, ReNet18, and ResNet50, were implemented for multi-object vehicle detection. Among these detectors, ResNet18 demonstrated superior performance, with an average precision of 96.16 and a log-average miss rate of 19.40. The results were then compared with a parking space template to identify vehicle occupancy information. Notably, Yolo, Yolo-conv, GoogleNet, and ResNet18 proved to be computationally efficient for real-time detection, while ResNet50 exhibited higher computational demands.

Detecting parked vehicles using surveillance cameras is challenging due to obstructions, lighting variations, varying viewing angles, and other considerations. In [12], an illegal parking detection method was conducted using a static camera with two types of backgrounds created from videos with different frame rates for two types of durations. This research approaches region-based segmentation of foreground objects using motion statistics as well as comparison of new frames against the background, where this method overcomes motion and lighting variations in the image. Study [13] performed car detection using OpenCV with Viola-Jones algorithm and Haar-Cascade classification with a strong classifier to remove objects other than cars. In addition, study [14] used deep learning and Detectron2 for parking lot occupancy detection from surveillance camera images. The dataset was processed for training a prediction model with Faster R-CNN architecture. The results obtained are quite good, but further improvements are still needed such as parameter variations and other CNN models such as Fast R-CNN, RetinaNet, and other CNN models. Other research done by Manase et al. in [15] to develop a smart parking system for roadside parking lots, aiming to ease the process of finding available parking slots for drivers. The method involved using CCTV cameras and implementing two detection techniques: Haar Cascade Classifier and YOLOv3. The study conducted tests in various scenarios, involving cars entering, exiting, and parking in the roadside area. The Haar Cascade Classifier achieved an average accuracy of 63.34%, while YOLOv3 demonstrated superior accuracy at 96.88%. These results indicate that the YOLOv3 method, specifically with ImageAI, outperformed the Haar Cascade Classifier in accurately detecting parked cars in different scenarios.

METHODS

Proposed System Design

In an effort to address the problem of on-street parking in Yogyakarta City, we propose a detection and warning system that integrates parking detection technology with a real-time warning mechanism. The system is designed to provide information to motorists who park illegally as well as provide alerts to related parties such as the Transportation Department and traffic police. Figure 3 is the workflow of the proposed system.

The initial stage of parking detection is done by performing inference to localize the vehicle using a classification model. This parking detection system receives input in the form of a surveillance camera image at a location with a configuration in the form of a classification model, Region of Interest (ROI), Intersection over Union (IoU) threshold, and stop time threshold, and waiting time threshold. Localization is performed to determine the initial position of the vehicle within the ROI. Then, if no movement is detected by the movement tracker, the stop timer is started. A parking detection message will be sent by this system to the alert system if the stopping time is more than the specified threshold.

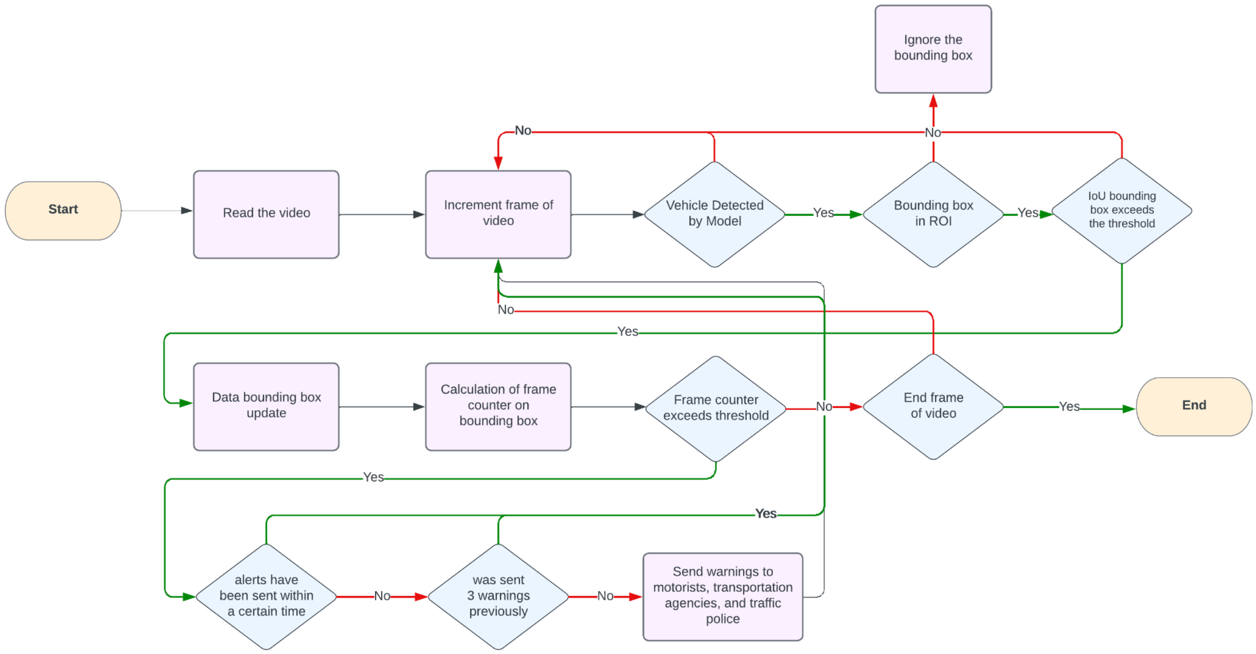

FIGURE 3. Flowchart of vehicle detection and movement tracking and alert system.

The waiting time is used to avoid sending repeated parking detection messages in a short period of time so that the next message will only be given after the waiting time. The system will stop all time calculations and send a safe message if there are no vehicles detected stopped by the movement tracker.

The alert system works when it receives an input in the form of a parking detection message that is sent along with a description of the location of the surveillance camera, as well as the time the parking vehicle was detected. The configuration of this system is within the tolerance of the number of messages received. These alerts are sent in the form of triggers to activate warnings to motorists through loudspeakers located in the relevant area, as well as to the monitoring department at the Department of Transportation and local traffic police in the form of notifications. If there are still more than the tolerable number of parking detection messages received, traffic police are deployed to enforce enforcement and also regulate traffic to avoid vehicle accumulation in the affected area.

Dataset

Dataset used in this study contains CCTV recordings from several roads in Yogyakarta City on the Terban road, especially between the UGM Roundabout and the Mirota Campus C intersection. The dataset is private and obtained from the Department of Transportation of Yogyakarta City. Simanjuntak which focuses from east to west (East of Mirota Intersection) and Gejayan road especially south of Demangan Market which focuses from north to south (South of Demangan Market). This data was obtained from the official website cctv.jogjakota.go.id which provides livestreams from various surveillance cameras in Yogyakarta City from August 14, 2023 at 12:06:40 WIB until 17:25:15 WIB and on August 15, 2023 at 12:32:01 WIB until August 16, 2023 at 02:46:11 WIB for East of Mirota Intersection and from August 16, 2023 at 13:19:06 WIB until August 17, 2023 at 06:08:02 WIB.

The dataset includes footage from two different time conditions, namely day and night. This allows the detection system to be tested under a variety of different lighting conditions, including challenges such as low lighting at night [16]. The dataset also includes footage from two different points of view. This is done to ensure that the detection model can recognize parked vehicles from different shooting positions, making the detection results more robust and general [17]. Details of the data used are listed in Table I with the samples listed in Figure 5 and Figure 6.

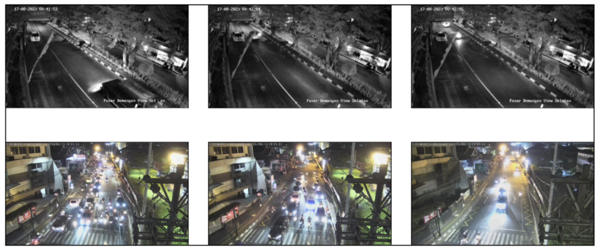

FIGURE 5. Sample dataset at night at (a) south of Demangan Market and (b) Mirota Kampus C intersection. Simanjuntak.

FIGURE 6. Daytime dataset samples at (a) south of Demangan Market and (b) Mirota Kampus C intersection. Simanjuntak.

This data is also accompanied by annotations labeling whether or not the vehicle is parked on the road. For ease of experimentation, it was assumed that vehicles that were considered as parked were those that stopped on the side of the road for more than 1 minute. This annotation process was done manually to ensure that the dataset had accurate and consistent labels. The details of the labeling done are listed in Table I.

TABLE I. Number of data for each case

Scenario	Location	Data Labels	
		Parking	No Parking
Malam	East of Mirota Intersection	4 videos	5 videos
Siang	East of Mirota Intersection	4 videos	5 videos
Malam	South of Demangan Market	4 videos	5 videos
Siang	South of Demangan Market	4 videos	5 videos

Vehicle Detection

In this system, a vehicle classification model is used with a performance comparison between several versions of YOLO and Haar Cascade. These models have their own advantages and characteristics. We use YOLO because this model has high speed and good accuracy, suitable for detecting vehicles in images or videos that can minimize errors and response time [18]. YOLO has several versions. We will also compare this performance with Haar Cascade which uses Haar-like features to identify objects based on patterns in images at high speed [19]. Haar Cascade is chosen as an alternative to compare the performance with YOLO in terms of detection accuracy and speed [20].

In this study, we experiment with 4 different types of vehicle detection models, namely, YOLO version 5 medium (YOLOv5-medium), YOLO version 5 large (YOLOv5-large) YOLO version 7 tiny (YOLOv7-tiny) and Haar Cascade. YOLOv5 uses CSPDarknet53 as the main feature extractor and also includes additional modules such as spatial pyramid pooling, PANet path-aggregation neck, and the same head from YOLOv4 [21] can detect various image size scales because this model is a fully convolutional neural network model [22] and has a focus layer that can reduce the number of layers and parameters so as to increase speed. YOLOv5-medium and YOLOv5-large are variations on this YOLOv5 model [23]. The difference between these variations is the size of the model, where YOLOv5-medium is a lighter YOLOv5 model compared to YOLOv5-large [24]. YOLOv7-tiny has a main computational block in the form of Extended Efficient Layer Aggregation Network (E-ELAN) [25] and there is a compound model scaling capability that allows the model to optimize model width (number of channels), model depth (number of stages), and resolution (input image size) [26]. Haar Cascade (HC) uses Haar-like features to perform classification and it is the lightest and fastest model for object detection [27]. Details of the models used in this study are listed in Table II.

TABLE Ⅱ. Models used

Model	*Model Type*
1	YOLOv5-medium
2	YOLOv5-large
3	YOLOv7-tiny
4	Haar Cascade

Movement Tracking

To detect whether a vehicle is parked or localized in a video, we use the IoU tracking algorithm to detect movement. This method utilizes the comparison between the IoU areas between two consecutive image frames to measure how far the object being tracked has moved. The tracking process begins by obtaining a bounding box to localize the vehicle, with the identification of the same vehicle indicated by the presence of a high IoU.

If the IoU of the bounding box of the vehicle in the current frame with the bounding box in the previous frame exceeds the IoU threshold, then the vehicle in the bounding box in that frame is the same vehicle as the vehicle in the bounding box in the previous frame and the vehicle is said to be stopped. In situations involving red traffic, it is important to note that the stop time caused by traffic lights typically does not affect the system's calculation of parking status, as the threshold for IoU frame counter is set larger than the usual red traffic stop time. In the parking detection system, the parking state is obtained if the safe state in the area covered by the CCTV is indicated by the overall IoU being below the threshold after existence

To prevent the break in stop time calculation due to frames that do not have a bounding box, we implemented an algorithm that adopts the concept of Grace Period. In this algorithm, the decision about movement tracking is not only based on the bounding box of one previous frame. However, the latest bounding box can compare itself with several previous frames based on a certain patience threshold.

Evaluation

The test was conducted to ensure that the model used in the parking detection system can detect vehicles parked in a predetermined area with optimal computation. This evaluation was conducted using manually annotated data labels to compare with the model's detection results as well as comparing the model's processing performance. Positive labels were assigned to parking categories. The evaluation metric used is accuracy which is calculated using accuracy, given by:

$$\frac{TP+TN}{TP+TN+FP+TN}$$

where TP is True Positive, TN is True Negative, FP is False Positive, and FN is False Negative [28].

RESULTS AND DISCUSSION

Based on the trials of each model used, the performance of each model is obtained as listed in Table III. High accuracy performance indicates the accuracy of the model in detecting whether or not the vehicle is parked, while high FPS indicates the level of capability of the model to process CCTV images.

In this trial and evaluation, model 2 demonstrated optimal accuracy performance that was also efficient. Although the FPS processing speed was lower than the other models, it was still effective. This is due to the need to balance between the smoothness of the video display and the detection of cars in the parking lot. An FPS of 5 is sufficient to detect important moments such as cars walking or stopping.

TABLE Ⅲ. Comparison of accuracy and fps performance on each model

Model	Accuracy	FPS
1	72,2%	6,7
2	86,1%	5,5
3	66,7%	14,2
4	61,1%	16,7

Based on Table III, model 1 and model 2 provide better accuracy performance. This is because these models have a larger number of layers and model parameters so that they can capture vehicle patterns in the image. Model 3 provides less optimal performance due to the smaller number of layers and parameters so that the vehicle patterns in the image cannot be detected properly. Although model 4 is a model that can make predictions with a very large FPS value, this model provides the worst performance compared to other models. Based on our evaluation, we decided to use model 2 (YOLOv5-large) as the model to be integrated in this system. Model 2 as a model that has the largest number of layers and parameters can detect vehicles in great detail without losing the ability to detect parking in real-time, very suitable for our case study with many parked vehicles far from CCTV cameras with the optimal number of FPS.

In the context of our application, an accuracy of 86.1% is considered sufficient for the system's requirements. Despite having a slightly lower Frames Per Second (FPS) compared to other models, model 2's accuracy performance indicates its effectiveness in correctly detecting parked vehicles. This accuracy rate means that the system correctly identifies parked vehicles in the majority of cases, ensuring that essential moments such as cars stopping or moving are captured accurately. These results are considered satisfactory because false positive detections will also be reviewed by local regulators, they are not directly subject to violations by the system.

The results of parking detection performed using model 2 are shown in Figure 7. An indication that this system detects a parked vehicle is indicated by the presence of a red bounding box and if the vehicle only passes through the road, there is only a green bounding box trace and the vehicle is not detected as parked. These results indicate that the model has good performance.

FIGURE 7. Results of vehicle detection, movement tracking, and labeling of parking on vehicles by Model 2

The proposed system presents a unique and innovative approach to on-street parking management in Yogyakarta City. While similar vehicle detection solutions exist in the literature, the uniqueness of this system lies in its integration of parking detection technology with a real-time warning mechanism. The system not only detects illegally parked vehicles but also alerts related parties, such as the Transportation Department and traffic police, in real-time.

One significant scientific contribution is the utilization of a combination of models (YOLOv5-large, YOLOv5-medium, YOLOv7-tiny, and Haar Cascade) for vehicle detection, allowing for a comprehensive comparison of accuracy and processing speed. Through this comparative analysis, the study identifies the YOLOv5-large model as the most suitable for the application, balancing accuracy and real-time processing effectively.

Additionally, the incorporation of the Intersection over Union (IoU) tracking algorithm to determine vehicle movement adds a layer of complexity and accuracy to the parking detection system. The introduction of the Grace Period concept, where the latest bounding box compares itself with several previous frames based on a patience threshold, enhances the system's ability to handle varying traffic conditions.

Furthermore, the study's unique dataset, sourced from specific locations in Yogyakarta City under different lighting and viewing conditions, ensures that the developed models are robust and adaptable to real-world scenarios. The manual annotation of the dataset guarantees accurate and consistent labels, enhancing the reliability of the evaluation

CONCLUSION

The results of data analysis show that a common cause of congestion on congested roads in Jogja City is on-street parking, especially on the roadside. Therefore, the proposed system is designed to detect roadside parking and provide solutions in the form of warnings to motorists and authorities. In performing parking detection, the YOLOv5-large model integrated with the IoU tracking algorithm provides optimal performance with high accuracy and capable frames per second.

To optimize the use of this system in Yogyakarta City which has various types of vehicles, such as becak, becak motor, delman, and andong, training with additional data is required. This training aims to improve the system's ability to detect various types of vehicles with high accuracy. In addition, suggestions for other uses of the system include better maintenance of CCTV, implementation of centralized computing using a graphics processing unit (GPU), and installation of loudspeakers. The use of good CCTV will support quality data acquisition, while centralized computing can improve the performance of the system, while loudspeakers can be used to provide warnings to drivers who park carelessly, thus assisting in the enforcement of regulations and prevention of further congestion.

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