Computer Vision Assisted Artificial Intelligence Enabled Smart Traffic Control System for Urban Transportation Management

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Abstract - Nowadays, computer Vision (CV) and Artificial Intelligence (AI) technologies in traffic management systems has emerged as a potential solution to alleviate traffic-related issues in metropolitan and urban cities. This research presents a novel approach called a Smart Traffic Control System for Urban Transportation Management (STC-UTM), which employs YOLO V8 as the development platform and Raspberry Pi 4 B single-board computer as the deployment platform. YOLO's real-time processing capabilities accurately identify various elements in the traffic environment, including cars, pedestrians, and bicycles. The Raspberry Pi 4 B, equipped with a powerful Graphics Processing Unit (GPU) does real-time data processing and utilizes AI algorithms to make adaptive decisions depending on traffic conditions. These choices include implementing adaptive traffic signal management, detecting congestion, and implementing rerouting schemes to improve vehicle flow and reduce traffic bottlenecks. The STC-UTM framework optimizes resource allocation, resulting in decreased travel time, fuel consumption, and environmental effects. The YOLO V8 model created has achieved a significant F1 score of 0.9634 and a recall rate of 0.9776, demonstrating its exceptional performance. The outcomes of this research have the potential to completely transform traffic management and urban transportation systems, providing advantages in terms of shortened journey durations, diminished environmental consequences, and improved road security.

Index Terms - artificial intelligence, computer vision, object detection, smart traffic, urbanization, LoRaWAN.

I. INTRODUCTION

The urbanisation process has resulted in a significant increase in the number of vehicles on the road, putting pressure on the current traffic infrastructure and causing a rise in the occurrence of accidents and deaths due to traffic. Conventional traffic management systems, which often depend on inflexible schedules and basic sensors, must be improved in dealing with urban traffic's ever-changing and unexpected characteristics. Artificial Intelligence (AI) and Computer Vision (CV) technologies have facilitated the development of sophisticated traffic management systems that can analyse data in real-time, make adaptive decisions, and implement proactive traffic control measures [1,2].

This research proposes a new method to tackle the intricate issues of contemporary transportation in metropolitan areas by using artificial intelligence and the YOLO V8 (You Only Look Once version 8) object detection framework to improve traffic management. Raspberry Pi 4B single-board Graphics Processing Unit (GPU) computer and the No Infrared (NoIR) camera module are used to develop the proposed intelligent traffic control system. The STC-UTM framework continuously monitors traffic conditions and dynamically controls the movement of vehicles in real-time. We examine the potential applications of AI-powered traffic management, focusing on its impact on traffic efficiency, safety, and environmental sustainability. The YOLO framework and Deep Learning (DL) techniques achieve real-time object identification and categorisation. The custom-built AI model processes the real-time object identification data to adapt traffic signal timings to provide real-time changes to variable signs. The primary objective of this research is to enhance the efficiency of traffic movement, mitigate congestion, and enhance safety. Dynamic traffic control systems that use vehicle counting from many directions at a junction are essential for optimising traffic flow, promoting safety, and improving urban transportation management. The primary contributions of this research are:

1. Using computer vision and image processing techniques can record video footage of the traffic and quantify the number of vehicles.
2. AI and Machine Learning (ML) algorithms can eliminate unwanted interference, such as people and non-vehicular objects, to achieve precise vehicle counting.
3. Dynamic traffic control systems constantly examine real-time data promptly, determine the timing of traffic signals, and synchronise with other traffic control units using LoRAWAN communication.

Accurate vehicle counting systems that can handle traffic from several directions are crucial for the administration of urban transportation. With the continuous advancement of technology, these systems will become more complex and indispensable for achieving more innovative and sustainable

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urban life. The system's capacity to adjust to fluctuating traffic circumstances and actively control signals can significantly boost traffic efficiency, alleviate congestion, bolster road safety, and contribute to developing ecologically sustainable transportation systems. The subsequent sections of the paper are organized in this manner. Section 2 of this paper outlines the significant research studies, section 3 explains the proposed technique, and the fourth section presents the experimental results, followed by the research conclusion.

II. RELATED WORK

The rising number of vehicles, increased urbanization, and growing concerns about traffic congestion, safety, and environmental sustainability have led to a surge in research and development efforts focused on creating innovative solutions. M Saleem et al. [3] introduced a fusion-based intelligent traffic congestion management system using ML to gather traffic data and route traffic on accessible routes. The proposed technology offers novel services to drivers to remotely observe traffic flow and vehicle volume to prevent traffic bottlenecks. Recent research has used AI and Computer Vision (CV) to develop models that can recognize different types of vehicles, enabling more precise traffic control and monitoring [4,5]. Many researchers emphasize integrating traffic control systems with broader smart city initiatives [6,7]. These integrated systems can communicate with public transportation networks, provide real-time data to drivers, and help with overall urban planning and management. According to P Chiradeja et al. [8], smart city public illumination systems should include Internet of Things (IoT) applications, air pollution monitoring, security system-based video surveillance, and flood warning systems.

The Internet of Things revolutionizes smart city infrastructure, but it presents challenges such as dense data nodes and network congestion. S Ibrahim et al. [9] propose adaptive aggregation techniques based on IoT traffic types to reduce packet congestion and reduce recurring packet headers. A new dynamic traffic congestion pricing and electric car charging management system for the Internet of Vehicles (IoV) in smart cities is proposed by Nyothiri Aung et al. [10]. A token management system that acts as a virtual currency, where cars earn tokens by using alternate, non-congested routes and charging stations to pay for charging. The Urban Traffic Control (UTC) system is a smart road traffic control management system designed to address the increasing issue of road intersections and traffic congestion in smart cities developed by Alkhatib et al. [11]. Their methodologies include vehicle counting, controlling processes, and evaluating lanes based on status. The system uses indicators and models such as lane weight, traffic jam indicator, and vehicle priority to assign traffic flow plans with minimal congestion and waiting time.

Several studies have investigated the integration of AI and computer vision for real-time traffic flow optimization [12,13]. These systems dynamically adjust traffic signal timings and manage traffic congestion by analyzing traffic patterns. Adaptive traffic signal control algorithms, often based on reinforcement learning, have demonstrated promising results in improving traffic flow and reducing wait times. Researchers have explored using computer vision to identify accidents, hazardous road conditions, and traffic violations. These systems can significantly reduce the response time of emergency services and mitigate the impact of accidents. Khan et al. [14] present a smart traffic management (STM) system that manages junction traffic loads using the Internet of Vehicles and game theory. Their STM managed traffic loads at uncontrolled junctions better than conventional procedures, lowering intersection traffic intensity by 30% and average waiting time by 40%. Integrating AI and computer vision in smart traffic control systems is poised to offer innovative solutions to the complex challenges of urban traffic management. The reviewed literature underscores the potential of these systems to optimize traffic flow, enhance safety, and promote environmental sustainability in urban areas. However, deploying such systems requires a multi-disciplinary approach involving computer vision, machine learning, real-time data processing, and collaboration between researchers and government authorities.

III. METHODOLOGY AND DESIGN

The current traffic conditions at the crossroads and the main routes impacted by this circumstance are consistent with the indications identified in this research. The junction will make the choice based on factors such as traffic volume and the priority of vehicles at the previous and subsequent intersections. The goal is to optimize traffic flow and reduce vehicle waiting time and congestion in the network. The YOLO V8 is a leading computer vision model designed to exhibit high speed, precision, and user-friendliness for object recognition, classification, and segmentation tasks. This model can endure training using extensive datasets and operate on several hardware platforms, ranging from central processing units (CPUs) to GPUs. The proposed model has been trained using publicly accessible data and a customized dataset encompassing a range of vehicles, including bicycles. The developed model is installed on a Raspberry Pi 4B single-board computer (SBC) with GPU acceleration. The Raspberry Pi 4B has a powerful quad-core ARM Cortex-A72 CPU, allowing it to handle YOLO inference tasks efficiently, especially with lower-resolution inputs. Despite the absence of a traditional GPU, the Raspberry Pi is furnished with a VideoCore VI GPU capable of performing specific machine learning tasks and neural network inferencing. The Raspberry Pi is well recognized for its use in IoT and edge computing applications. Moreover, the presence of hardware acceleration and software optimizations might have a substantial influence on the speed of YOLO V8 on a Raspberry Pi.

Traffic congestion is increasing in metropolitan centres globally, resulting in prolonged travel durations, higher fuel usage, and elevated environmental pollution. To tackle this problem, we have devised an intelligent and instantaneous traffic light control system that can promptly adapt to the prevailing traffic circumstances, as shown in Fig 1. YOLO is a cutting-edge deep-learning model capable of real-time object detection and localization in pictures or video frames. By instructing YOLO to train to identify bicycles, automobiles, trucks, and people, it can deliver uninterrupted and up-to-date information on the traffic conditions at a traffic signal point. By integrating computer vision methods, this data enables the real-time management of traffic lights. The dynamic traffic signal control system comprises many essential components that make up its architecture.

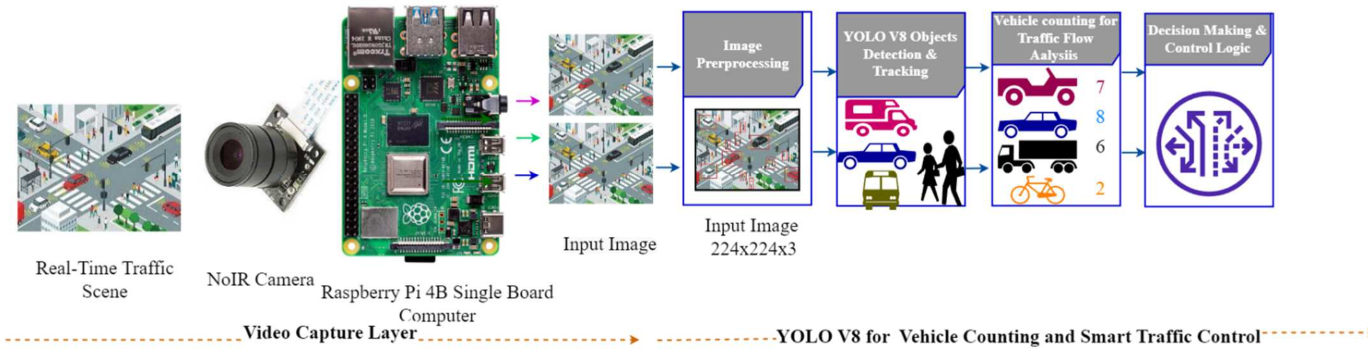


Fig. 1. The architecture of the proposed computer vision-assisted artificial intelligence-enabled smart traffic control system.

The NoIR camera, equipped with the CSI protocol, captures real-time video footage and can function well in low-light environments and foggy atmospheres. This is especially crucial for controlling and regulating traffic at nighttime or in places with inadequate lighting and provides unobstructed views of cars and pedestrians. Conventional visible light cameras perform poorly while dealing with the intense brightness emitted by headlights, particularly in low-light conditions. NoIR cameras are less susceptible to the adverse effects of glare, hence assuring the visibility of license plates and vehicle information for traffic monitoring and enforcement. Unlike visible light cameras, no-infrared cameras provide superior capability in penetrating certain weather situations, such as mild fog, haze, and smoke. It is crucial to provide traffic management under unfavourable weather conditions. To summarize, NoIR cameras are ideal for traffic intersections because they can eliminate glare-related problems, enhance object identification capabilities, and successfully operate in unfavourable weather conditions.

The YOLO V8 perform object recognition on the incoming video stream and transmits the identified object data to the Object Recognition and Counting Module (ORCM). The ORCM algorithm analyzes the object data, identifying and monitoring objects as they change. The YOLO algorithm detects and categorizes automobiles in every video stream frame to count the number of vehicles at a traffic light. YOLO can differentiate between automobiles and other things, such as people, signs, or structures and applies bounding boxes to identify and outline each observed vehicle. The bounding boxes delineate the precise region inside the picture where each vehicle is located. Upon identifying vehicles in the current frame, YOLO V8 compares these bounding boxes with those observed in the previous frame. YOLO can ascertain the entry or departure of a vehicle in the frame by examining the overlap or intersection of the bounding boxes. This data allows the monitoring of the trajectory of vehicles over a while. When used with a counting algorithm, the YOLO method can accurately determine the number of automobiles by monitoring the vehicles that enter the frame and subtracting those that depart. Each time a vehicle's bounding box enters the frame, it is incremented in the count, and when it departs, it is decremented from the count. This reasoning aids in precisely estimating the number of vehicles queued at the traffic light. The YOLO algorithm and the counting logic are tuned to operate in real-time and accurately track the movement and any alterations in-vehicle locations during this brief timeframe. Vehicle counting is but one facet of the capabilities of such a system, with the overarching objective being the optimization of traffic movement and the mitigation of congestion at crossings.

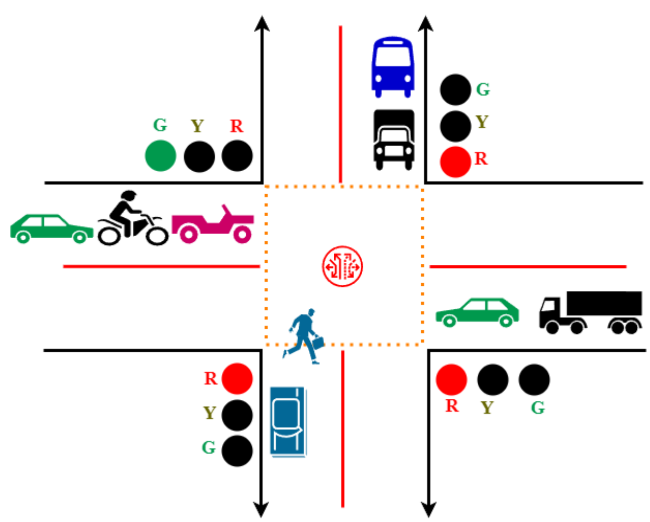


Fig. 2. A schematic of the real-time smart traffic control junction has been used in this research.

A schematic of the smart traffic control junction is presented in Fig 2. The Traffic Management Logic processes the data, formulates judgments and transmits instructions to the traffic control devices or lights. The technology utilizes vehicle count data to comprehend traffic patterns at the crossing. This research examines the hours with the highest traffic volume, the traffic concentration, and the frequency of vehicles. The traffic management system will adaptively modify traffic signal timings based on real-time vehicle count data. During periods of heavy traffic volume, the system can prolong the duration of the green light on the major route, facilitating the passage of more vehicles. During low traffic, the system can decrease the duration of the green light on the main route to minimize waiting times and save energy. In the event of congestion, the system can prioritize lanes with more vehicles to ease traffic. A short calculation for calculating junction traffic delay times using the formula:

$$Wt = (Na / (2 * Ml)) * (1 - (1 + (2 * Ml / Vn)) \qquad (1)$$

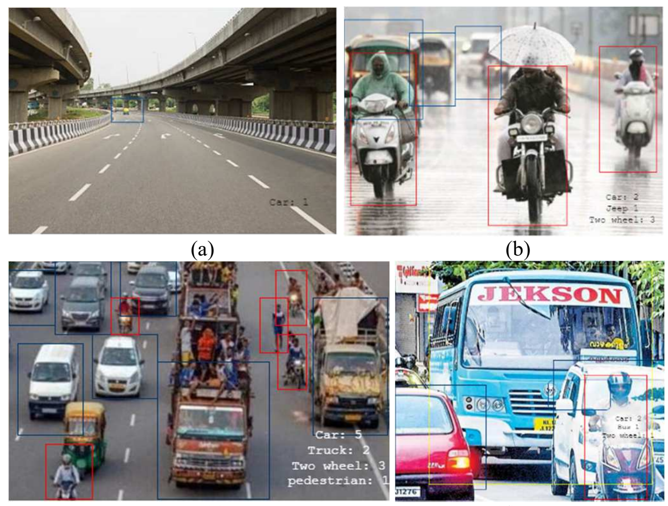
Where Wt is the time spent waiting due to traffic, Na is the number of vehicles that arrive in a specific time interval, Ml represents the mean length of vehicles, and Vn is the number of vehicles that pass through the junction in a given time.

When the number of vehicles waiting in line is beyond a specific limit, it prompts the system to modify the duration of traffic signals, allocating additional time for the corresponding direction to alleviate the accumulation of vehicles. For instance, when the system detects a sudden rise in the number of cars approaching a certain direction, it can promptly adjust the timing of traffic signals to accommodate this increased traffic and alleviate congestion. For instance, a dramatic reduction in the number of vehicles might suggest the occurrence of an accident or the closing of a route. In such instances, the system can automatically modify signal timings to facilitate the swift passage of emergency vehicles. The process iterates incessantly, adjusting to fluctuating traffic circumstances and formulating instant decision-making.

Long Range Wide Area Network (LoRAWAN) is a wireless communication technology for low-power, long-range connectivity and is suitable for IoT applications, such as smart traffic control systems [15]. The camera sensors positioned at the junction collect real-time data on traffic conditions. The data include information on the number of automobiles, the flow of traffic, and the categorization of vehicles. The traffic signal controller employs the LoRaWAN network for transmitting data and issuing control commands to a central server, facilitating the surveillance of adjacent signals within a 5 to 10-kilometer radius. A central server or gateway processes the data and provides a real-time presentation of traffic conditions and traffic signal statuses for traffic control operators. These changes will include adjustments to signal timings, prioritizing of emergency vehicles, or adaptability to changing traffic conditions. The technology's extensive range enables the connection of traffic lights across a city, even in places with high urban density. LoRaWAN facilitates the immediate transmission of data between traffic signal controllers and central servers, enabling prompt reactions to dynamic traffic situations. In future endeavours, LoRaWAN can be merged with additional environmental monitoring and air pollution sensors such as CO2, PM 2.5, temperature, humidity, and light levels [16].

IV. RESULTS AND DISCUSSION

Urbanization has resulted in several challenges with traffic congestion, air pollution, and transportation efficiency. We suggest a cutting-edge approach incorporating computer vision and artificial intelligence into traffic management systems to tackle these difficulties. AI-powered traffic control systems can adapt signal timing to current traffic conditions. This guarantees that traffic lights adapt to variations in traffic volume and congestion, thereby reducing waiting times and enhancing traffic circulation. Decreased traffic congestion and better traffic flow reduce vehicle emissions; hence, improving air quality in metropolitan regions and reducing fuel consumption and carbon emissions aligns with sustainability and environmental objectives.



(a) (b) (c) (d)

Fig. 3. Real-time vehicle counting using YOLO V8 model a) less traffic, b) rainy/foggy atmosphere, c) mixed set of vehicles and d) ambient atmosphere with multi-class vehicles.

Fig 3 shows various test images with different environmental conditions, including rainy or foggy climates. When evaluating the performance of the model for vehicle recognition and counting using YOLO V8, true positive (T^+), true negative (T^-), false positive (F^+), and false negative (F^-) are used. T^+ refers to the instances when the model accurately identifies and counts automobiles. T^- is not often considered and is less significant because YOLO mainly focuses on detecting objects and does not make predictions for non-vehicles. F^+ is the number of objects the model incorrectly classifies as automobiles, even when not, and F- occurs when the YOLO model cannot accurately identify and accurately count cars in the scenario. These are used to compute precision, recall, accuracy, and F1-score, which aid in evaluating the efficacy of the YOLO model in tasks related to vehicle recognition and counting.

$$\text{Accuracy } (Ac) = (T^+ + T^-) / (T^+ + T^- + F^+ + F^-) \qquad (2)$$

$$\text{Precision } (Pr) = T^+ / (T^+ + F^+) \qquad (3)$$

$$\text{Sensitivity/Recall } (Re) = T^+ / (T^+ + F^-) \qquad (4)$$

$$\text{F1 Score} = 2^* (Pr * Re) / (Pr + Re) \quad (5)$$

TABLE 1. PERFORMANCE ANALYSIS OF THE YOLO V8 MODEL IN RASPBERRY PI 4 B GPU COMPUTER.

SI No.	Object Class	Accuracy	Precision	Recall	F1 score
1	Bi-cycle	95.38	95.28	97.80	96.52
2	Bus	94.22	94.02	97.35	95.65
3	Car	95.66	95.83	97.87	96.84
4	Jeep	95.38	94.65	98.71	96.64
5	Pedestrian	96.24	95.88	98.73	97.29
6	Truck	97.96	95.48	97.37	96.42

Table 1 demonstrates that the developed model has attained a high F1 score (0.9634) and recall rate (0.9776), indicating optimum performance. We possess real-time access to video feeds from mobile cameras and NoIR cameras positioned at different traffic locations for evaluating the vehicle counting framework. Following the testing phase, we have refined the YOLO V8 model to enhance counting precision and minimize occurrences of both false positives and false negatives. Optimal performance is attained for instantaneous processing by considering variables such as frame rate, latency, and processing load on the hardware unit.

V. CONCLUSION

The research highlights the capabilities of a smart traffic control system that integrates computer vision and artificial intelligence. The YOLO V8 object detection model and the Raspberry Pi 4 B are used to impact the field of urban traffic management efficiently. This method exemplifies the revolutionary potential of contemporary technology in tackling the intricate issues related to urban transportation. The backbone of this intelligent traffic management system relies on YOLO's capacity to precisely detect and classify different aspects of the traffic environment, including automobiles and pedestrians. Raspberry Pi 4 B, with its powerful GPU and computing capabilities, is suitable for real-time data processing and AI algorithm execution. This feature allows data-driven choices, including adaptive traffic signal management, congestion monitoring, and on-the-fly traffic rerouting to optimize traffic flow and reduce congestion. Urban planners and officials working to improve transportation infrastructure and policy could benefit from the system's real-time data analysis and traffic flexibility. The system utilizes CV and AI technology to improve traffic management, shorter journey durations, lower environmental consequences, and greater road safety. Finally, integrating YOLO and Raspberry Pi 4 B inside a smart traffic control system highlights the significance of technological advancement in influencing the trajectory of urban transportation.

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