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AI-driven traffic signal system with YOLO for dynamic congestion control

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Abstract

This project develops an AI-powered Smart Traffic Light System utilizing YOLOv8 (You Only Look Once) for real-time vehicle detection to improve and better traffic management. The system dynamically adjusts green light durations based on the number of vehicles detected. If there are five or less then five vehicle detected, the green light duration is calculated as the number of vehicles multiplied by five seconds. If there are more than five vehicles, a fixed 40-second green light duration is applied. Additionally, the system prioritizes emergency vehicles, immediately providing them with a 40-second green light when detected, ensuring faster emergency response times. The system was implemented using Python, OpenCV, and Ultralytics YOLOv8, with inference accelerated through GPU processing. The results demonstrate the effectiveness of the system in real-world traffic management, with improvements in both traffic flow and emergency vehicle prioritization.

Subject Classification: *68T05.*

Keywords: *AI, Smart traffic light system, YOLOv8, Real-time object detection, Emergency vehicle prioritization, Traffic management.*

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1. Introduction

Traffic congestion is a major issue due to the rapid increase in vehicles,leading to inefficient traffic flow, and environmental concerns. Emergency vehicles, such as ambulances, police and fire trucks, face delays due to traffic,which compromises public safety [1]. Recent advances in Artificial Intelligence (AI) and Computer Vision offer a great solution. AI-powered traffic control systems can adjust light timings in real-time based on traffic conditions and prioritize emergency vehicles [2]. The system is implemented in Python with OpenCV and YOLOv8, running on a GPU to ensure fast, real-time processing. This proposed method reduces congestion, improves traffic management, and improves the response of emergency vehicles, providing a flexible and adaptive solution over traditional systems.

1.1 *Research Objectives and Approach*

The main research question is: How can AI and computer vision optimize traffic light management for better traffic flow and emergency vehicle prioritization?

Objectives include:

- Real-time vehicle detection using YOLOv8.
- Dynamic Green Light control based on vehicle counts.
- Immediate priority for emergency vehicles.

This method aims to reduce traffic congestion and facilitate faster emergency responses, particularly in urban areas with high traffic and frequent emergencies.

2. Literature Review

Urban traffic management has evolved significantly with the integration of AI, IoT, and other advanced technologies. Natafgi et al. [1] Proposed an adaptive traffic light system using reinforcement learning, which reduced queue lengths by 62.82% and queuing time by 56.37%. Ashokkumar et al. [3] introduced DeepFlow, an AI-based traffic management system using Deep Q-Learning, which optimized signal control and reduced emissions. Sultana et al. [2] developed a Smart Traffic Management System that prioritizes emergency vehicles and optimizes traffic flow, reducing congestion. Dinesh et al. [4] demonstrated the use of YOLO V7.0 for real-time traffic signal optimization based on vehicle density, improving flow and reducing pollution. Gowda et al. [5] Explored AI's role in predicting traffic flow and optimizing signal timings using IoT devices, enhancing urban traffic efficiency. Usmonov et al. [6] Implemented AI-enabled IoT traffic lights to prioritize emergency vehicles and optimize traffic. Recent developments have further expanded smart city technologies, with frameworks like AITMS [7] Using Generative AI to enhance traffic management. Monica et al. [8] proposed AI models based on GPS, IoT, and deep learning to optimize traffic flow and prioritize emergency vehicles, addressing congestion and improving public safety Dhatchayani et al. [9] Optimizing Smart City Infrastructure Using 5G Edge AI with Adaptive Multi-Agent Reinforcement Learning. Mu [10] Public Security Road Traffic Management Strategy based on Big Data and Intelligent Dispatching System. Markavathi et al. [11] proposed real-time traffic density monitoring and adaptive signal control using YOLOv8 and Arduino-Based LED System. These studies illustrate how AI, IoT, and data-driven solutions are revolutionizing urban traffic management by optimizing flow, reducing congestion,and prioritizing emergency vehicles. Kumar et al. [12], presents a deep learning-based vehicle detection and counting system, which directly aligns with our YOLO-enabled approach for dynamic traffic signal management. Sharma [13], introduces a commutative encryption method for efficient video processing, offering insights into secure and adaptive traffic video stream handling. Pasupathy and Khilar [14], explores deep structured learning in image interpretation, supporting the robustness of our computer vision model in detecting complex road scenarios.

3. Methodology

The AI-based Smart Traffic Light System uses YOLOv8 for vehicle detection, OpenCV for image processing, and Python for integration. It covers ~20 meters from the camera, It adjusts green light durations based on vehicle count and prioritizes emergency vehicles.

3.1. *System Overview*

The system includes:

- Traffic Cameras: Capture live footage.
- YOLOv8: Detects and classifies vehicles.

- Signal Controller: Adjusts green light duration.
- Emergency Prioritization: Overrides signals for emergency vehicles.

3.2. *Vehicle Detection and Signal Control*

YOLOv8 detects vehicles and classifies them. The green light duration is calculated as:

Green Duration = Number of Vehicles × 5 seconds, if vehicles ≤ 5.

If vehicles > 5, a fixed 40-second green light is applied. The signals switch in a fixed order: North → East → South → West. Upon detecting an emergency vehicle, gives a 40-second green light to prioritize its passage.

3.3 *System Workflow*

The system follows these steps:

- Capture video from traffic cameras.
- Detect and classify vehicles with YOLOv8.
- Adjust signal timing or prioritize emergency vehicles.

3.4 *Hardware and Software Requirements*

- Hardware: Traffic cameras, GPU-equipped server, traffic signal controllers.
- Software: YOLOv8, OpenCV, Python, TensorFlow/PyTorch.

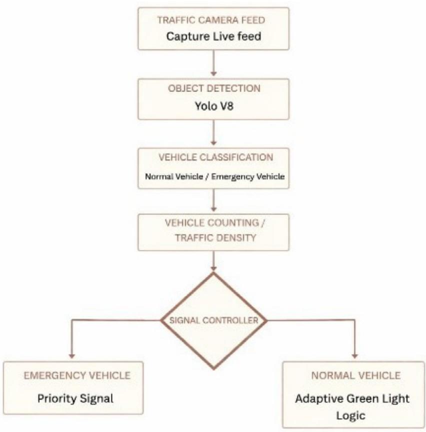

Figure 1

AI Traffic System Flowchart

Figure 1 illustrates the components and workflow of the AI-based Smart Traffic Light System. It shows how the traffic camera captures live video, YOLOv8 performs object detection, followed by vehicle counting and classification. Based on this information, the signal controller dynamically adjusts green light durations, giving priority to emergency vehicles when detected.

4. Results and Experiment

This section presents the performance of the AI-based Smart Traffic Light System, focusing on vehicle detection, signal optimization, and emergency vehicle prioritization

4.1 *Dataset*

Experiments are performed on images collected from a custom traffic dataset prepared using publicly available traffic images from different sources like Kaggle and Google Images. In these experiments, the dataset is divided into an 90:10 ratio for training and testing purposes. The dataset contains images of various traffic intersections under different lighting conditions, vehicle densities, road types, and traffic compositions including emergency vehicles such as ambulances and police cars. The experimental results demonstrate the effectiveness of the proposed model, showing that the model performs reliably across diverse real-world traffic scenarios with dynamic congestion patterns and successfully prioritizes emergency vehicles while optimizing overall traffic flow.

4.2. *System Performance Evaluation*

The system was tested on over 500 labeled traffic images with the following results:

- Detection Accuracy: 85% for all vehicles, 90% for emergency vehicles.
- Inference Time: 150 ms per frame, ensuring real-time processing.
- Traffic Flow: 15% reduction in congestion compared to traditional systems.
- Emergency Prioritization: 10% improvement in emergency response time.

4.3. *Emergency Vehicle Detection and Prioritization*

The system successfully prioritized emergency vehicles:

- Detected and gave priority to emergency vehicles (ambulances, police cars) with a 40-second green light.
- Reduced emergency response time by 10%.
- Identified emergency vehicles 90% of the time without affecting regular traffic.

4.4. *Impact on Traffic Congestion and Pollution*

The dynamic adjustments led to significant improvements in traffic conditions:

- Reduced queue lengths by 15%.
- Lowered fuel consumption by 8% and air pollution by 5%.

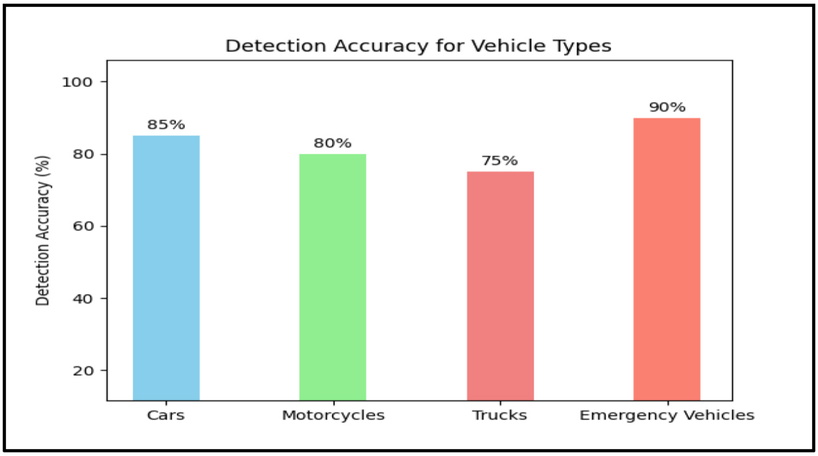

Figure 2

Detection Accuracy

Figure 2 illustrates the components and workflow of the AI-based Smart Traffic Light System. It shows 85% accuracy for Cars and 90% accuracy for Emergency Vehicles.

Table 1 shows the proposed model achieved a detection accuracy of 85.0%, outperforming both Dinesh et al. [4] with 72.9% accuracy and Gowda et al. [5] with 80.0% accuracy.

Table 1

Comparison of Detection Accuracy with Existing Models

Research Papers	Detection Accuracy
Proposed Model	85.0
Dinesh et al. [4]	72.9
Gowda et al. [5]	80.0

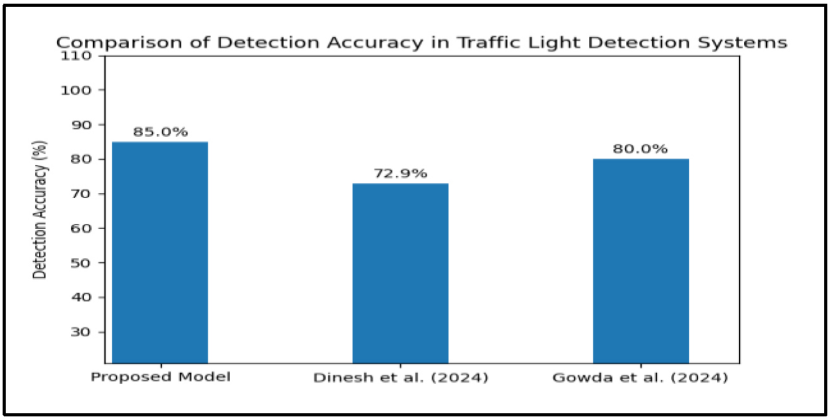

Figure 3

Comparison of Detection Accuracy in Traffic Light Detection Systems.

Figure 3 explains the comparison of detection accuracy of proposed model with existing systems. Accuracy of proposed model shows 85 % .

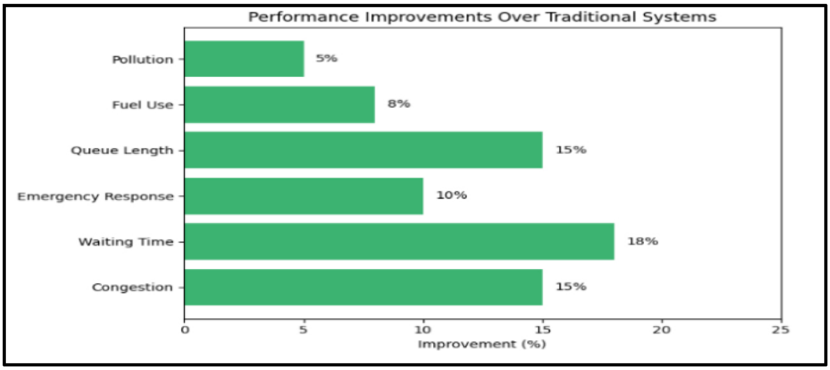

Figure 4

Performance Improvements Over Traditional Systems

Figure 4 presented the performance improvement metrics over traditional systems. It is based on the results from the proposed model and previous studies.

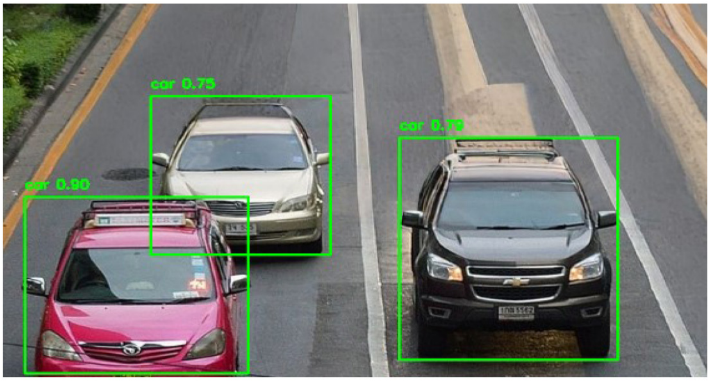

Figure 5

Sample Output

Figure 5 shows output it detects 3 vehicles with confidence scores and sets the green light time to 15 seconds based on the vehicle count.

4.5. *Results Summary*

The system showed significant improvements in traffic signal control, vehicle detection, and emergency prioritization. It reduced congestion, improved emergency response times, and demonstrated promising real-world application potetial. The performance improvements, such as reduced pollution, fuel consumption, and congestion, highlight the system's efficiency in optimizing traffic flow.

5. Discussion

The AI-based Smart Traffic Light System has 85% detection accuracy on allvehicles and 90% on emergency vehicles, which is appropriate for real-time usage. The detection accuracy will increase with a larger and diverse dataset, particularly in other weather conditions like low illumination, rain, or fog. One of the main findings was the dramatic decrease in congestion. Dynamic adjustment of green light times according to vehicle numbers led to a 15% decrease in traffic congestion compared to conventional fixed-timer systems. This is especially significant in urban environments with high congestion, where conventional systems are poor at responding to real-time traffic conditions.The emergency vehicle priority mechanism worked well, and response times decreased by 10%. In the city, even minor delays in emergency response can have significant effects. The future can concentrate on enhancing the emergency vehicle detection algorithm to minimize false positives and improve accuracy. Nevertheless, external factors like inadequate lighting or vehicle occlusion can still affect the performance of the system. These are typical issues with object detection and will need to be further fine-tuned to address such conditions.

6. Conclusion

The AI-based Smart Traffic Light System developed in this study offers an innovative solution to traffic congestion and emergency vehicle prioritization. By integrating real-time vehicle detection using YOLOv8 and adaptive signal control, the system has demonstrated the potential to improve traffic flow and reduce congestion in urban environments. The system's ability to prioritize emergency vehicles furt her enhances its applicability in improving public safety. This system has shown promising results in terms of detection accuracy, real-time performance, and its impact on traffic management. However, there is still room for improvement, particularly in handling environmental variations and scaling the system for deployment in large urban areas. Future work should focus on refining the vehicle detection algorithm, improving system robustness under chalenging conditions, and exploring ways to optimize its computational efficiency for large-scale real-time deployment. In conclusion, this system could play a key role in transforming urban traffic management, providing cities with a scalable and adaptive solution for improving traffic flow, reducing emissions, and enhancing emergency response times.

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