

Intelligent Traffic Signal Optimization Using Image Processing and Canny Edge Detection for Density-Based Traffic Management

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Abstract- — Traffic congestion has become a major challenge in urban transportation systems due to the increasing number of vehicles on roads. Conventional traffic signal systems generally operate on fixed timers, which often results in inefficient traffic management and unnecessary waiting time at intersections. To address this issue, an intelligent traffic control system based on image processing techniques is proposed. The system captures real-time traffic images using surveillance cameras and processes them to estimate vehicle density. The captured images undergo preprocessing operations such as grayscale conversion and noise reduction before applying the Canny edge detection algorithm to identify vehicle edges. The density of vehicles is determined by calculating the number of edge pixels in the processed image and comparing them with a reference image. In addition, the You Only Look Once (YOLO) object detection algorithm is used to identify emergency vehicles such as ambulances and provide them with priority signal allocation. Based on the estimated traffic density, the system dynamically adjusts traffic signal duration for each lane. The proposed approach improves traffic flow efficiency, reduces waiting time, and enhances emergency vehicle movement at intersections. This intelligent system can serve as a practical solution for modern smart city traffic management.

Index Terms: Traffic Density Estimation, Image Processing, Canny Edge Detection, YOLO Object Detection, Smart Traffic Control, Intelligent Transportation Systems, Computer Vision.

I. INTRODUCTION

Traffic congestion has become one of the major challenges faced by modern urban transportation systems due to the rapid increase in the number of vehicles on roads. The growing population, economic development, and increased use of private vehicles have significantly contributed to the rise in traffic density, especially in metropolitan areas. As a result, road intersections frequently experience heavy congestion, leading to increased travel time, fuel consumption, and environmental pollution. Effective traffic management has therefore become an important requirement for ensuring smooth and efficient transportation in cities [8], [13].

Traditional traffic signal systems generally operate based on fixed timing mechanisms or manual control by traffic police. In timer-based systems, each lane is assigned a predetermined duration for green signals regardless of the actual number of vehicles present. Although such systems are simple to implement, they often fail to handle dynamic traffic conditions efficiently. When the traffic density varies between lanes, fixed signal timing may cause unnecessary waiting for vehicles in less congested lanes while heavily congested lanes remain

blocked. This limitation reduces the overall efficiency of traffic signal systems [2], [10].

With the advancement of digital technologies, image processing and computer vision techniques have emerged as effective solutions for intelligent traffic management. By installing surveillance cameras at intersections, real-time traffic images can be captured and analysed to determine the density of vehicles in each lane. Image processing techniques allow the system to identify vehicles and estimate traffic conditions without requiring expensive hardware sensors embedded in roads [8], [11].

One widely used technique in image processing is the Canny edge detection algorithm, which is capable of identifying edges and boundaries of objects in digital images. By applying this algorithm to traffic images, the edges of vehicles can be detected and used to estimate traffic density [1], [12]. In addition, modern object detection algorithms such as You Only Look Once (YOLO) enable the system to detect different types of vehicles, including emergency vehicles like ambulances. When such vehicles are identified, the traffic control system can prioritize them by providing immediate signal clearance. The proposed system introduces an intelligent traffic control mechanism that utilizes image processing techniques to

dynamically allocate signal timings based on real-time traffic density. The system processes traffic images, detects vehicle edges using Canny edge detection, and calculates the density of vehicles by analysing edge pixels. Furthermore, the integration of YOLO-based vehicle detection enables the system to identify emergency vehicles and provide them with priority access. This approach improves traffic signal efficiency, reduces congestion at intersections, and enhances emergency vehicle movement in urban road networks.

II. LITERATURE SURVEY

Researchers have proposed several intelligent traffic management techniques to address the increasing problem of traffic congestion in urban areas. Many of these methods utilize image processing, computer vision, and machine learning algorithms to analyse traffic conditions and optimize traffic signal control.

Anjani proposed a smart traffic control system using image processing techniques to measure traffic density. In this method, traffic images captured from surveillance cameras are processed using the Canny edge detection algorithm to identify vehicle edges. The number of detected edge pixels is compared with a reference image to determine traffic congestion levels, and the traffic signal timing is adjusted accordingly to improve traffic flow [1].

Tahmid introduced a density-based traffic control system that analyses multiple traffic scenarios using digital image processing techniques. In this approach, captured traffic images are compared with predefined reference images after applying edge detection operations. The similarity between the images is calculated to determine the level of congestion, and signal timing is dynamically allocated based on the traffic density of each lane. This approach helps in improving traffic signal management by responding to real-time traffic conditions [3].

Lee proposed a camera-based traffic monitoring system that estimates traffic density by analysing vehicle movement within a specific region over a certain time interval. The system utilizes image processing algorithms such as Canny edge detection to detect vehicle edges and estimate traffic flow patterns. By monitoring vehicle movement and density, the system is able to dynamically control traffic signals and reduce congestion at intersections [4].

Ramya proposed an intelligent traffic management framework that integrates image processing with fuzzy logic control. In this system, real-time traffic images captured from cameras are processed using the Canny edge detection algorithm to detect vehicle edges and calculate traffic density. The extracted

information is then provided as input to a fuzzy logic controller that determines the appropriate signal timing based on congestion levels, thereby reducing waiting time at traffic signals [5].

Jahanbakhsh proposed a traffic control approach that combines Canny edge detection with artificial neural networks to estimate the number of vehicles in each lane. In this method, the edge features extracted from traffic images are provided to a neural network model that predicts traffic density and adjusts signal timing accordingly. This technique improves traffic signal efficiency by predicting traffic patterns and controlling signals dynamically [6].

Rajkumar proposed a smart traffic control system that uses image processing techniques along with vehicle detection algorithms to monitor traffic conditions. The system uses camera-based monitoring and morphological operations to detect vehicles and estimate traffic density. Based on the calculated traffic density, signal timings are optimized to reduce congestion and improve traffic movement in urban areas [7].

From the above studies, it is evident that image processing and computer vision techniques play a significant role in developing intelligent traffic management systems [8], [11]. However, many existing approaches primarily focus on estimating traffic density and do not provide priority for emergency vehicles such as ambulances. Therefore, an improved traffic control system that integrates vehicle density estimation with emergency vehicle detection is required to enhance traffic signal efficiency and improve emergency response time.

III. SYSTEM ANALYSIS

A. Existing System

Traditional traffic control systems are primarily based on fixed-time traffic signals or manual monitoring by traffic police. In timer-based traffic signal systems, a fixed time interval is assigned to each lane regardless of the number of vehicles present. Although these systems are simple and widely used, they often fail to manage traffic efficiently during peak hours or uneven traffic distribution. This limitation leads to unnecessary waiting time for vehicles in less congested lanes while heavily congested lanes remain blocked.

In some cases, sensor-based traffic control systems are used where sensors such as infrared sensors or loop detectors are installed on roads to detect the presence of vehicles. These

systems help automate traffic signal control to some extent. However, such systems require expensive infrastructure, continuous maintenance, and physical installation of hardware on roads, which increases operational costs.

Recent research has introduced image-processing-based traffic monitoring systems where cameras capture images of road intersections and analyse traffic density using computer vision techniques. These systems use image processing algorithms to detect vehicles and estimate traffic congestion levels from captured traffic images [8], [10]. Although these approaches improve traffic monitoring capabilities, many existing systems mainly focus on estimating vehicle density and do not prioritize emergency vehicles such as ambulances or fire trucks. As a result, emergency vehicles may still experience delays at traffic intersections, which can affect emergency response time.

Disadvantages Of The Existing System

- **Fixed Signal Timing:**
Traditional traffic signal systems allocate a fixed duration for each lane regardless of actual traffic density, which leads to inefficient traffic flow and unnecessary waiting time.
- **Lack of Real-Time Traffic Analysis:**
Many existing systems are unable to analyze traffic conditions in real time and therefore cannot adapt to dynamic traffic patterns.
- **High Infrastructure Cost:**
Sensor-based traffic control systems require installation of specialized hardware devices on roads, which increases the cost of implementation and maintenance.
- **Inaccurate Vehicle Detection:**
In some cases, sensors may fail to accurately detect vehicles due to environmental factors such as weather conditions, road damage, or sensor malfunction.
- **No Emergency Vehicle Priority:**
Most traditional traffic systems treat all vehicles equally and do not provide priority to emergency vehicles such as ambulances.
- **Limited Scalability:**
As the number of vehicles increases, traditional systems struggle to efficiently manage traffic flow in large urban environments.

B. Proposed System

The proposed system introduces an intelligent traffic control mechanism based on image processing techniques to

dynamically manage traffic signals according to real-time traffic conditions. In this system, surveillance cameras are installed at traffic intersections to continuously capture images of road traffic.

The captured images are first pre-processed to improve image quality and converted into grayscale format. After preprocessing, the Canny edge detection algorithm is applied to detect the edges of vehicles present in the image. The number of edge pixels obtained after applying the algorithm is used to estimate the traffic density of each lane [1], [12].

To enhance system performance, the YOLO (You Only Look Once) object detection algorithm is used to detect different types of vehicles, including emergency vehicles such as ambulances. When an ambulance is detected, the system immediately prioritizes that lane by allocating a green signal to allow faster movement.

Based on the estimated vehicle density and comparison with reference images, the system dynamically determines the appropriate green signal duration for each lane. This adaptive traffic signal control approach helps reduce congestion, minimize waiting time at intersections, and improve the overall efficiency of traffic management systems in urban environments.

IV. SYSTEM DESIGN

System Architecture

Below diagram depicts the whole system architecture.

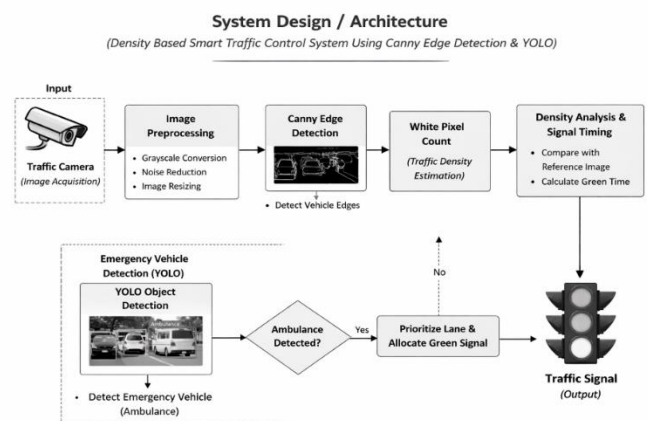


Fig 1. Methodology followed for proposed model

V. SYSTEM IMPLEMENTATION MODULES

This section outlines the core implementation modules of the proposed intelligent traffic signal optimization system using image processing techniques. The system follows a modular pipeline consisting of traffic image acquisition, preprocessing, vehicle detection, edge detection, traffic density estimation, and dynamic traffic signal allocation. This structured design improves traffic monitoring accuracy, enhances real-time traffic management, and reduces congestion at road intersections.

A. Traffic Image Collection and Preprocessing Module:

The Traffic Image Collection and Preprocessing Module is responsible for capturing traffic images using surveillance cameras installed near road intersections. These cameras continuously monitor the traffic flow and capture images of vehicles present in different lanes. The captured images provide real-time traffic information that is used for further analysis. Since raw traffic images may contain noise, lighting variations, and background disturbances, preprocessing operations are applied to improve image quality. These preprocessing techniques include resizing the images to a standard resolution, converting the images into grayscale format, and applying noise reduction filters. These steps help improve the clarity of the images and prepare them for accurate vehicle detection and traffic density estimation using computer vision techniques [8], [13].

B. Vehicle Detection Module using YOLO Algorithm:

The Vehicle Detection Module identifies vehicles present in the captured traffic images using the YOLO (You Only Look Once) object detection algorithm. YOLO is a deep learning-based object detection technique capable of detecting multiple objects in real time with high accuracy.

The algorithm divides the input image into a grid structure and predicts bounding boxes around detected objects along with their class probabilities. Using this method, the system detects various types of vehicles such as cars, buses, motorcycles, and emergency vehicles like ambulances. Detecting emergency vehicles is particularly important in intelligent traffic systems because it allows the system to provide priority signal allocation for emergency services. The YOLO algorithm is widely used for real-time traffic monitoring due to its high detection speed and efficiency [8], [11].

C. Edge Detection Module using Canny Algorithm:

After detecting vehicles, the system applies the Canny Edge Detection algorithm to identify the boundaries of objects present in the traffic image. Edge detection is an important step in image processing as it highlights object boundaries by detecting significant intensity changes between neighboring pixels.

The Canny edge detection algorithm performs multiple steps including noise reduction, gradient calculation, non-maximum suppression, and edge tracking using hysteresis thresholding. The output of this process is a binary image where vehicle edges appear as white pixels against a dark background. These detected edges represent the outlines of vehicles present in the traffic scene and are used to estimate traffic density levels in each lane. The Canny algorithm is widely used in traffic monitoring systems due to its robustness and ability to detect accurate object boundaries [1], [12].

D. Traffic Density Estimation Module:

The Traffic Density Estimation Module calculates the level of congestion in each lane based on the number of detected edge pixels. After applying the Canny edge detection algorithm, the resulting binary image contains white pixels that represent the edges of vehicles.

The system counts the total number of these white pixels to estimate the density of vehicles present in the captured traffic image. The calculated density value is then compared with a reference image representing heavy traffic conditions. Based on the similarity between the captured image and the reference image, the system determines the level of congestion in each lane. This density-based approach allows the system to dynamically monitor traffic conditions and identify heavily congested lanes [3], [10].

E. Dynamic Traffic Signal Allocation Module:

The Dynamic Traffic Signal Allocation Module determines the appropriate green signal duration for each lane based on the estimated traffic density. Lanes with higher traffic density are assigned longer green signal durations, while lanes with lower traffic density receive shorter signal durations.

Additionally, when the YOLO algorithm detects an ambulance or emergency vehicle, the system automatically prioritizes that lane by providing immediate signal clearance. This feature ensures faster movement of emergency vehicles and improves emergency response time. By dynamically adjusting signal

durations based on real-time traffic conditions, the proposed system improves traffic flow efficiency and reduces congestion at road intersections.

VI. RESULTS AND DISCUSSION

This section presents the experimental results and performance evaluation of the proposed intelligent traffic signal optimization system using image processing techniques. Traffic images captured from surveillance cameras were processed using preprocessing techniques, YOLO-based vehicle detection, and Canny edge detection for traffic density estimation. The evaluation focuses on analysing vehicle detection performance, traffic density estimation accuracy, and the effectiveness of dynamic signal allocation in improving traffic flow efficiency at road intersections [1], [8], [11].

A. Vehicle Detection Performance using YOLO

The YOLO (You Only Look Once) algorithm was used to detect vehicles present in the captured traffic images. The system successfully identified multiple vehicle types such as cars, buses, motorcycles, and emergency vehicles. YOLO performs real-time object detection by dividing the input image into grid cells and predicting bounding boxes along with object class probabilities.

Experimental results show that the YOLO algorithm can accurately detect vehicles under various traffic conditions. The detected vehicle information allows the system to monitor traffic flow and identify emergency vehicles such as ambulances for priority signal allocation. Real-time vehicle detection techniques have been widely used in intelligent transportation systems to improve traffic monitoring and management [8], [13].

Table 1 presents sample vehicle detection results obtained from traffic images.

Table 1. Vehicle Detection Results

Image ID	Cars	Buses	Motorcycles	Ambulances	Total Vehicles
Image 1	12	2	5	0	19
Image 2	9	1	4	1	15

Image 3	15	3	6	0	24
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The results demonstrate that the YOLO algorithm effectively detects vehicles in real-time traffic environments and provides accurate vehicle classification information.

B. Traffic Density Estimation using Canny Edge Detection

To estimate traffic density, the system applies the Canny Edge Detection algorithm to the captured traffic images. The algorithm detects the edges of vehicles by identifying intensity variations between neighboring pixels. The resulting binary image highlights vehicle edges as white pixels against a dark background.

The number of white pixels detected in the processed image is used to estimate the level of traffic congestion in each lane. A higher number of edge pixels indicates a higher density of vehicles. This edge-based density estimation technique is widely used in image-processing-based traffic monitoring systems due to its efficiency and simplicity [1], [12].

Table 2 shows an example of traffic density estimation based on the number of detected edge pixels.

Table 2. Traffic Density Estimation

Lane	Edge Pixels	Traffic Density
Lane 1	3500	Medium
Lane 2	5200	High
Lane 3	2100	Low
Lane 4	4700	High

The results show that lanes with higher edge pixel counts correspond to higher vehicle density levels. This information is used by the system to dynamically adjust signal timing.

C. Dynamic Traffic Signal Allocation

Based on the estimated traffic density, the system dynamically adjusts the duration of traffic signals. Lanes with higher traffic density are allocated longer green signal durations, while lanes with lower traffic density receive shorter signal durations. This adaptive signal control mechanism helps reduce congestion and improves traffic flow at intersections.

In addition, the YOLO algorithm detects emergency vehicles such as ambulances and automatically prioritizes the corresponding lane by providing immediate signal clearance. This feature improves emergency response time and ensures faster movement of emergency vehicles through traffic intersections. Intelligent traffic management systems based on computer vision techniques have demonstrated significant improvements in traffic efficiency and emergency vehicle prioritization [3], [10].

Table 3 illustrates an example of signal duration allocation based on traffic density.

Table 3. Dynamic Traffic Signal Allocation

Lane	Traffic Density	Green Signal Duration
Lane 1	Medium	30 seconds
Lane 2	High	50 seconds
Lane 3	Low	20 seconds
Lane 4	High	45 seconds

The experimental results indicate that the proposed system can effectively optimize traffic signal timings according to real-time traffic conditions. The integration of vehicle detection and density estimation enables intelligent signal control, reducing waiting time and improving overall traffic management efficiency.

VII. CONCLUSION AND FUTURE WORK

This study proposed an intelligent traffic signal optimization system based on image processing and computer vision techniques for efficient traffic management at road intersections. The proposed system utilizes surveillance cameras to capture real-time traffic images and processes these images using the Canny edge detection algorithm to estimate vehicle density. The dataset consists of traffic images containing different types of vehicles, and the system analyses these images to determine the level of traffic congestion in each lane.

To improve traffic monitoring capabilities, the YOLO object detection algorithm was employed to identify vehicles in the captured images, including emergency vehicles such as ambulances. By integrating real-time vehicle detection with traffic density estimation, the system dynamically adjusts

traffic signal durations based on the detected congestion level. Experimental results demonstrate that the proposed system can effectively reduce waiting time at intersections and improve overall traffic flow efficiency in urban road networks [1], [3], [10].

Furthermore, the integration of computer vision techniques allows the system to provide priority signal allocation for emergency vehicles, ensuring faster response times during critical situations. This intelligent traffic management approach contributes to improved road safety and more efficient utilization of existing traffic infrastructure [8], [13].

Future work may focus on incorporating advanced deep learning models for more accurate vehicle detection and traffic density estimation. Additionally, the system can be extended by integrating Internet of Things (IoT) technologies and smart city infrastructure to enable real-time traffic monitoring and automated traffic signal control across multiple intersections. Cloud-based traffic management platforms and large-scale data analytics may further enhance the scalability and effectiveness of intelligent transportation systems.

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