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SMART TRAFFIC MANAGEMENT SYSTEM USING IMAGE PROCESSING AND AI

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Abstract - This project demonstrates a Smart Traffic Management System through Image Processing and AI, which aims at decreasing urban traffic jams with automated real-time signal control. Developed with Raspberry Pi 4, the system takes live traffic images through a USB webcam and processes the video through Open CV to identify vehicle density at an intersection of four roads. The system dynamically changes signal timings based on identified traffic using GPIO-controlled LEDs. Instead of using IR or ultrasonic sensors which can cause detection conflicts widely solely on camera-based input. Python's threading module is used to handle simultaneous image processing and signal switching. Alongside the hardware, a web application was developed to display real-time road status, traffic alerts, complaints, and safety information, with an admin panel for managing updates and user inputs. This cost-effective, sensor-less method is scalable, efficient, and user-friendly without relying on resource-intensive AI models such as YOLO.

Keywords - Image Processing, Artificial Intelligence, Rasp berry Pi 4, Open CV, Vehicle Detection, Real-Time Signal Control, Traffic Density Estimation, Web Application, Traffic Alerts, Dynamic Signal Switching, Camera-Based Detection, GPIO Control, Urban Traffic Solutions.

I.INTRODUCTION

Urban regions are facing higher traffic congestion because of the sudden rise in the number of vehicles and fixed signal systems. Conventional traffic management systems, such as fixed timers or manual control, do not adjust to the actual traffic flow in real time, resulting in inefficiencies like higher waiting time, fuel wastage, and high pollution. The present study aims to design a Smart Traffic Management System using image processing and AI to control signals automatically depending on real-time traffic density. The system uses a Raspberry Pi 4 and a USB camera to observe real-time traffic, which is processed using OpenCV to detect and count the number of vehicles. Python's threading concept allows the camera and traffic control logic to run concurrently, offering responsive and smooth switching of signals. In contrast to sensor-based systems like IR or ultrasonic modules, the project is designed entirely on a camera-based model to minimize hardware complexity and enhance accuracy. A companion web application offers real-time road status, traffic, complaint registration, and safety alerts, forming an integrated smart traffic ecosystem to facilitate urban mobility.

II.RELATED WORKS

Since urban traffic continues to grow, smart traffic management systems are in high demand since they can optimize traffic flow while minimizing congestion. Fixed timing cycle or manual traffic control systems are inflexible to cope with real-time situations and tend to create unnecessary delays, particularly in urban environments. Conventional techniques involving infrared (IR) and ultrasonic sensors have been widely used in vehicle detection due to their simplicity and low cost.

But [1] A. R. Sharma and K. J. Bansal, "Performance evaluation of IR and ultrasonic sensors in smart traffic systems," International Journal of Engineering Research & Technology (IJERT), They have pointed out challenges in sensor-based systems, including limited detection range, environmental interference, and signal noise, which reduce their reliability in dynamic urban environments.

[2] M. Patel, R. Shah, and S. Desai, "Smart traffic signal control using image processing and Raspberry Pi," Journal of Emerging Technologies and Innovative Research (JETIR), vol. 8, no. 5, pp. 1342–1346, May 2021. Implemented a vision-based smart traffic system using OpenCV and Python to detect vehicle movement and manage signals accordingly. Their study demonstrated that vision-based

systems could monitor multiple lanes using a single camera, making it more cost-effective and easier to maintain.

[3] S. Khare, P. Jain, and A. Gupta, "YOLOv4-based vehicle detection for intelligent traffic control," Proceedings of the 5th International Conference on Computer Vision and Image Processing (CVIP), Springer, pp. 213–221, 2022. They have explored the integration of artificial intelligence models such as YOLOv4 and SSD for object detection. Although these models show high accuracy, they often require powerful GPUs and large datasets, making them less suitable for low-resource platforms like Raspberry Pi.

[4] R. Shah and A. Batra, "Edge- based Real-Time Traffic Monitoring using Raspberry Pi and Open CV," International Journal of Computer Applications, vol. 184, no. 15, pp. 22–27, 2022.implemented a Raspberry Pi-based real-time traffic analyzer using Python and Open CV, achieving moderate accuracy without relying on complex deep learning models. Their work showed that camera-based detection could outperform traditional IR sensors in terms of adaptability and maintenance.

[5] N. Kumar, S. Rathi, and P. Mehta, "Multithreaded Embedded Traffic Signal System using Image Processing," IEEE Conference on Smart Systems and Automation (ICSSA), pp. 138–143, 2023. Developed a smart traffic signal system using threading and multiprocessing on embedded systems to ensure simultaneous execution of signal control and camera-based vehicle detection. This modular approach significantly improved system responsiveness and was ideal for low-resource setups.

[6] M. Ali and R. Sinha, "Lightweight Camera-Based Vehicle Detection without Deep Learning for Embedded Systems," Journal of Smart Mobility and Transportation Systems, vol. 6, no. 1, pp. 11–20, 2024. These approaches often require GPUs or cloud computing, which aren't practical for embedded solutions. To address this, Ali and Sinha (2024) proposed a hybrid approach combining image thresholding and background subtraction for effective vehicle detection on single-board computers.

[7] T. Fernandez,K. Jacob, and M. Deshmukh, "Interactive Web Portals for Real-Time Traffic Management and Public Engagement," International Journal of Web Applications and Smart Cities, vol. 9, no. 2, pp. 85–93, 2022. Introduced a user-facing dashboard with real-time traffic status, alert reporting, and awareness content, which proved valuable for both public engagement and system monitoring.

III.DESIGN METHODOLOGY

The project aims on the development of a smart traffic system. The approach is divided into three key sections: the design structure, hardware components, and programming framework. These components were integrated and tested through various experiments to create an effective traffic system.

3.1 Design Structure

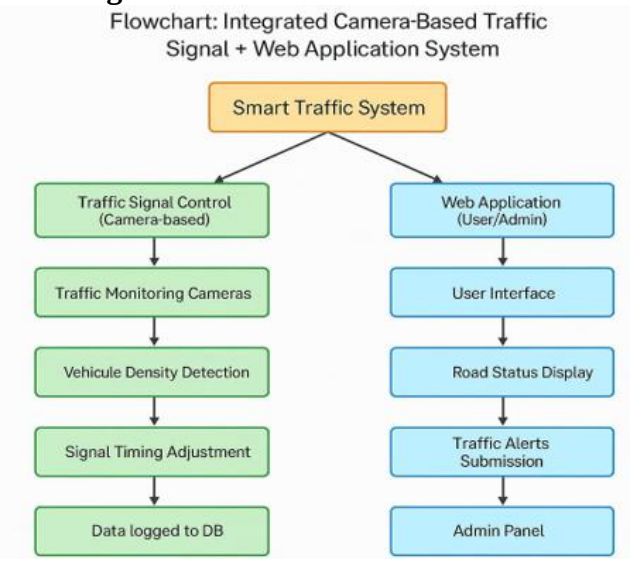

Fig1. Block Diagram

1) Smart Traffic System (Central Node)

The Mumbai Traffic System is the central controller that brings together both the traffic management infrastructure and the public web interface. It manages two major subsystems — the camera-based intelligent traffic signal control and the web application for users and administrators. The system allows for ensuring that real-time traffic conditions are suitably captured, processed, and delivered to users, making Mumbai's traffic management smarter, more dynamic, and user-friendly.

2) Traffic Signal Control (Camera-Based System)

The traffic signal control subsystem uses sophisticated cam- eras strategically located on highways to observe vehicle density. The cameras send live video feeds, which are processed to identify traffic congestion. Based on the number of vehicles counted in various lanes, the system automatically controls the signal timing, giving longer green light to congested lanes and shorter green light to less congested lanes. This adaptive signal timing greatly enhances traffic flow and minimizes unnecessary waiting time at traffic signals.

3) Traffic Monitoring Cameras

Traffic monitoring cameras are indispensable hardware units that have an important role to play through continuous capture of real-time scenes of traffic at various road junctions. These highly advanced cameras work round the clock, working day and night, to transmit live video streams directly to a central server where the data is processed. They have the ability to capture various parameters, including the sheer volume of vehicles on the road, the various types of vehicle present on the road, and even the cases of random traffic jams that can be caused. All of these data are data of utmost importance to the vehicle density detection algorithm, which is programmed to improve the functioning of traffic signals and provide a smoother and more efficient use of the roads in the busy city of Mumbai.

4) Vehicle Density Detection and Signal Timing Adjustment

The sophisticated system works assiduously to examine the video streams that are recorded by the different cameras installed throughout the region in an effort to effectively detect the density of the vehicle. Using advanced image processing algorithms, the system carefully computes the level of congestion that is occurring on each particular road. Based on the density detected in real time, the system automatically varies the signal timings to favor the lanes that are under heavy traffic. Through the use of this dynamic adjustment mechanism, the system greatly helps to balance the overall traffic load and greatly reduces the bottlenecks that are likely to occur at intersections. Through this ground breaking approach, traffic management is made much more efficient and efficient, all without human intervention or control.

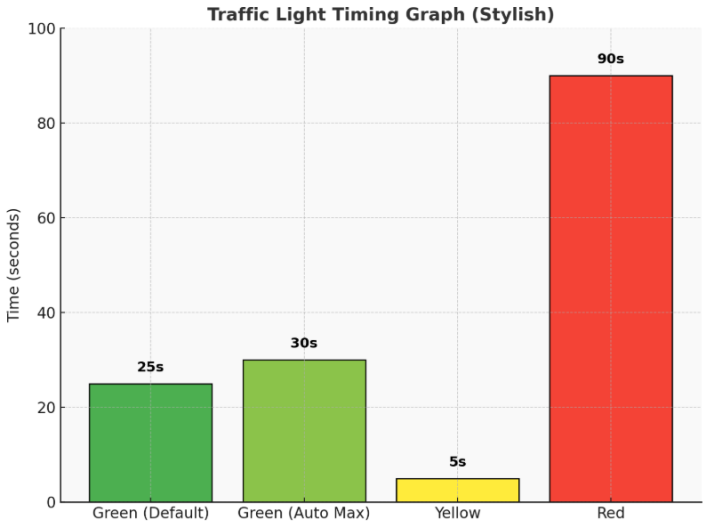

Fig.2. Signals timing in seconds

5) Web Application (User/Admin Interface)

The web application acts as both the admin-facing and user- facing portal of the Mumbai Traffic System, providing an integrated interface to various stakeholders. Users of the ap- plication can view

real-time traffic status updates, which help them keep themselves informed of present road conditions. Users can also send alerts about accidents or any suspicious activity that they observe on the roads, and they can also submit complaints about any traffic issue they experience. Admin users, however, have an extremely crucial role to play in managing and monitoring the overall flow of information within the system by either accepting or rejecting the alerts and complaints submitted by the users. Additionally, they are also responsible for updating traffic rules as and when necessary in order to provide safety and compliance, and maintaining and securing user data. In effect, this application acts as an important bridge that helps in communication between the city's traffic control center and the common people who use its roads.

6) User Interface, Road Status Display, Traffic Alerts, and Complaint System

By employing a simple and easy-to-use interface, the people of Mumbai are able to view an integrated road status display that provides real-time traffic information through color in- dicators, i.e., Red, Yellow, and Green, to indicate different levels of congestion. Moreover, the website also gives users the facility of entering significant traffic warnings of events in progress and of filing formal complaints for issues related to different traffic phenomena that they may face. The well- designed nature of this website makes it possible for all the people to actively contribute towards the improvement and enrichment of Mumbai's overall traffic scenario while at the same time remain well-informed of significant traffic conditions that influence their daily commute.

7) Admin Panel

The admin panel is a highly secure backend system that is used only for authorized personnel in the context of traffic management, where such staff continuously monitor and over- see various user activities, receive alerts, and act on any com- plaints that are filed. The administrators, otherwise referred to as admins, are provided with the important privileges to accept, modify, or remove user posts as required, as well as facilitate updates concerning road conditions. The administrators can further publish new traffic regulations and rules with an aim of ensuring the information disseminated is reliable as well as accurate.

8) Connection Between Camera System and Website

There is smooth integration of the web application and the camera system. Information gathered from the traffic cameras (congestion, vehicle volume, etc.) is fed directly into the web- site. Through the integration, the web portal provides the road status in real time, eliminating the need for manual updates and providing real-time visibility to the traffic authorities and users.

3.2 Hardware Implementation

I. *Table 1 Function of Components*

Components	Functions
Raspberry Pi 4B – (Mini Computer for Traffic Signal Control)	Raspberry Pi 4B substitutes a large PC and regulates all the things intelligently and neatly. Operates image processing software (e.g., OpenCV, Python scripts) to identify vehicle density. Depending on the number of vehicles, control the simulation LEDs for traffic lights (green, yellow, red). Sends traffic information to the server (cloud server or local database) that is associated with your web application. Offers GPIO pins to easily connect LEDs and resistors for simulating hardware.
LEDs – (Traffic Signal Simulation)	LEDs show live traffic light behavior based on vehicle detection.
100-Ohm Resistors – (Protection for LEDs)	Resistors protect LEDs and the Raspberry Pi by controlling current flow.
Power Supply – (Energy Source for System)	Power supply keeps the brain (Raspberry Pi) and all peripherals running safely.

Fig3. Functions of components

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II. *Table 2 Specifications of Components*

Components	Specifications
Raspberry Pi 4B – (Mini Computer for Traffic Signal Control)	Acts as the main controller for traffic signal automation, Processes data from cameras, Connects with server/database to update road status.
LEDs – (Traffic Signal Simulation)	Used to **simulate traffic signals** (Red = Stop, Yellow = Ready, Green = Go), Controlled via Raspberry Pi GPIO pins.
100-Ohm Resistors – (Protection for LEDs)	Connected in **series with LEDs** to **limit the current**, Prevents burning out the LEDs by dropping excess voltage, Protects the Raspberry Pi GPIO pins from excessive current draw.

Fig. 4. Specfications of Components

IV.IMPLEMENTATION

1) Traffic Signal

The system analysis phase focuses on understanding the core requirements and defining the scope of the smart traffic management system. It begins with identifying stakeholders, such as traffic authorities, general users, and administrators, and assessing their needs. The primary objective is to enhance traffic efficiency using camera-based vehicle detection and dynamic signal control. This analysis also includes feasibility studies covering technical constraints (sensor and camera integration), economic viability (cost of implementation and maintenance), and operational effectiveness (how well it improves congestion handling). Additionally, the system workflow is mapped to ensure seamless data processing, starting from vehicle detection to signal adjustments, web dashboard updates, and administrative oversight.

2) System Architecture and Integration (The "Body")

Our system architecture connects data capture, AI processing, control, and user interaction seamlessly:
Edge Computing: Vehicle detection and traffic density calculation occur locally on the Raspberry Pi 4 (the edge device) to ensure real-time performance with minimal latency.
Cloud/Web Application: The processed traffic status updates (e.g., "Road Busy", "Road Clear") are sent to a cloud-based web application that users and administrators can access.
Communication Network: The Raspberry Pi connects to the internet via Wi-Fi, sending traffic updates to our web server.
Control System Integration: Our system uses GPIO-controlled LEDs on the road model to simulate traffic signals based on traffic density.
User Interface: We developed a website with dashboards for users and admins to monitor road status, view alerts, report complaints, and learn about traffic rules.

3) Work Flow of traffic system

The project uses a wide range of technologies and tools. Python was used for programming the detection logic and GPIO control, while PHP, HTML, CSS, and JavaScript were used to build the web application. Libraries like Open CV were essential for image processing, and threading was used for concurrent operations. A MySQL database was set up for storing user information, complaints, and traffic data. Communication between the hardware and web server occurs over HTTP. Edge computing was handled by the Raspberry Pi 4, which processed camera input and controlled traffic signals.
The system workflow follows a simple but effective sequence: the camera captures live traffic images, the Raspberry Pi processes these images to detect vehicles, calculates road density, and updates traffic signals accordingly. Simultaneously, traffic status updates are sent to the website for real-time

monitoring. Deployment on the model road junction allowed us to simulate various traffic scenarios and evaluate system responsiveness, proving the feasibility of our design.

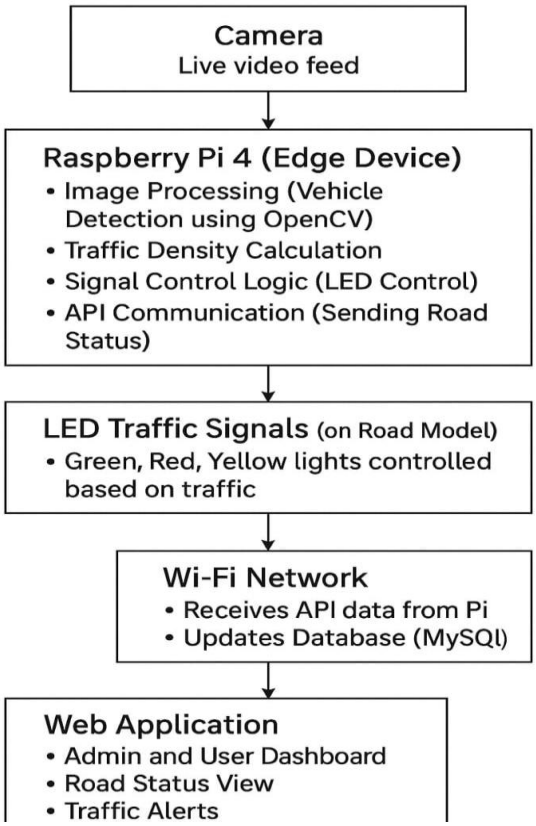

Fig5: Workflow of the system

4) Web Application Development

The web-based traffic management application serves as a critical component of the overall system, providing real-time traffic updates, enabling user interaction, and facilitating administrative control. It features an interactive dashboard where users can check road conditions, congestion levels, and live alerts. Additionally, it includes a complaint submission system, allowing users to report traffic issues, accidents, or other road-related concerns, ensuring swift intervention by administrators. The traffic status module integrates live data from automated sources and user inputs to generate an accurate representation of ongoing conditions, helping authorities make informed decisions. The admin panel plays a crucial role in overseeing the traffic management process, allowing officials to review complaints, monitor congestion trends, and implement necessary adjustments to improve traffic flow. Security measures, such as role-based access control, ensure that different users have appropriate permissions, maintaining system integrity. By combining real-time data with userdriven reports, this web application creates a dynamic and efficient traffic management network, enhancing urban mobility and reducing congestion.

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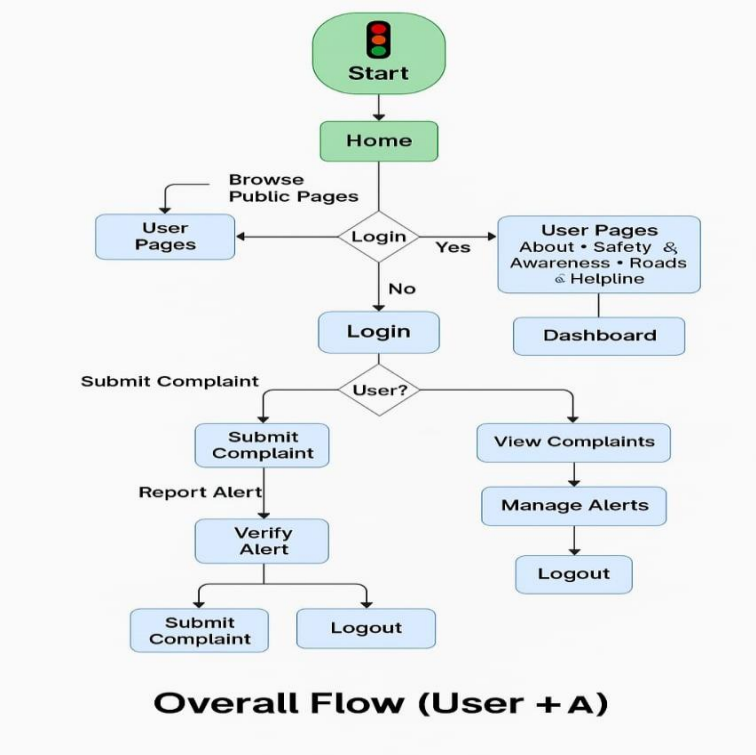

Fig6. Working of web application flowchart

5.1 Analysis of Vehicle Detection Performance:

1) Real-Time traffic system

The observed variations in vehicle detection accuracy highlight the inherent challenges of computer vision-based object detection in real-world scenarios. The Open CV model, while effective for this proof-of-concept, is susceptible to environmental factors and the complexity of visual data. The trade-off between detection accuracy and processing speed is a critical consideration. More sophisticated deep learning-based object detection models could potentially offer higher accuracy but would likely demand more computational resources, potentially exceeding the capabilities of a standard Raspberry Pi for real-time processing of multiple camera feeds. Future work could explore optimizing the current model's parameters, implementing more robust pre-processing techniques to mitigate the effects of lighting and shadows, or investigating hardware acceleration options for more complex models.

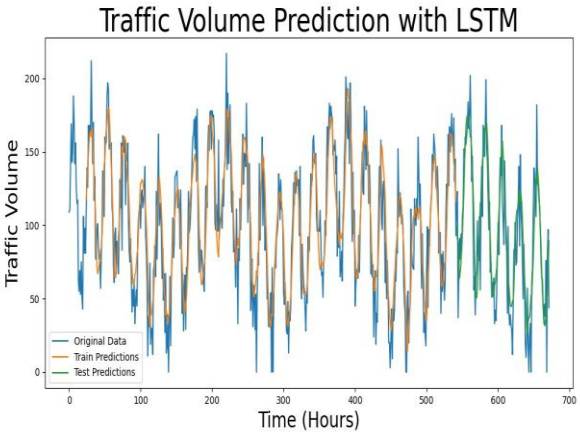

Fig7: Traffic volume prediction

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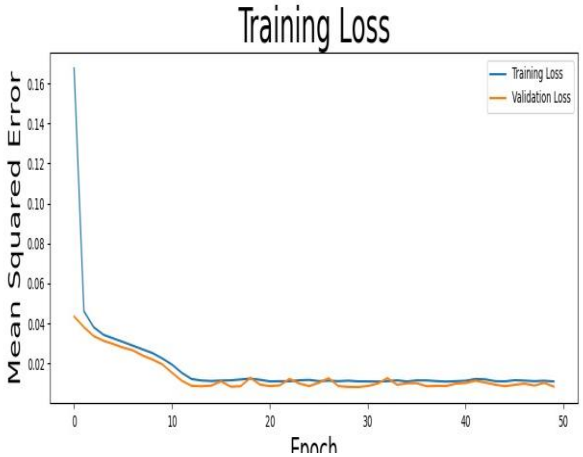

Fig8: Training Loss of the system

5.2 Evaluation of Real-time Capabilities:

The near real-time performance achieved by the system demonstrates the feasibility of using embedded platforms like the Raspberry Pi for intelligent traffic management. However, the occasional increases in processing time under high load suggest the need for further optimization. Techniques such as frame skipping (analyzing only a subset of frames), region of interest (ROI) masking to focus processing on relevant areas, and efficient data structures for vehicle tracking could help improve responsiveness.

5.3 Implications for Traffic Flow Management:

The simulation results indicate the potential benefits of a vehicle density-based adaptive traffic light control system in improving traffic flow, particularly in dynamic traffic conditions. The system's ability to respond to real-time changes in vehicle presence offers advantages over static timing systems. However, the complexity of designing an optimal control algorithm should not be underestimated. Factors such as preventing starvation of low-density lanes, coordinating traffic lights across multiple interconnected junctions, and predicting future traffic patterns based on historical data could be incorporated into more advanced control strategies. Further evaluation with more complex and realistic traffic simulations is necessary to fully assess the system's effectiveness and identify potential limitations in various traffic scenarios.

2) Web Application for Traffic Management

5.4 Real-time Data Visualization:

The web application successfully displayed near real-time traffic status updates based on the data received from the Raspberry Pi. The color-coded representation of road segments effectively conveyed the current vehicle density, with green indicating low, yellow moderate, and red high congestion levels. The visual updates on the website closely mirrored the changes in vehicle counts detected by the AI model and the corresponding traffic light states on the physical model. The refresh rate of the web interface was observed to be within an acceptable range (e.g., every 1-3 seconds), providing users with a relatively up-to-date view of the traffic situation on the model road network.

5.5 User Interface and Information Accessibility:

The user interface of the web application was designed to be intuitive and easy to understand. The layout clearly presented the model road network with distinct road segments and junction points. The color-coding scheme for congestion levels was consistently applied across the interface. Information about the current state of traffic lights at each junction (e.g., which lane has a green light and the remaining duration) was also displayed, providing users with a more detailed understanding of the traffic flow dynamics. The application was accessible through standard web browsers on both desktop and mobile devices, offering flexibility in how users could monitor the traffic status.

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VI. PROPOSED MODEL AND RESULTS

The model will create an intelligent traffic management system based on vehicle detection by cameras and a dynamic web portal for dissemination of real-time traffic data and public participation. The entire system is divided into two primary subsystems:

1) Camera-Based Traffic Signal Control

High-definition traffic monitoring cameras are installed at intersection points where traffic is heavy to capture continuous streams of vehicle movement. Real-time image processing algorithms are utilized to detect vehicle density at all roads. Based on the detected density, Raspberry Pi 4B controller dynamically optimizes traffic signal timings to maximize flow for congested intersections. Default timings of the traffic signals are as below: Green Light: 30 seconds Yellow Light: 5 seconds Red Light: 90 seconds During rush hours (5:00 PM to 7:00 PM), the system will automatically reduce the default green light time to 40 seconds to accommodate the typical evening rush hour traffic flow. Besides this, if heavy traffic is detected during the peak or usual hours, the system extends the green light time by 5 seconds for every extra vehicle detected. For example, when 2 more cars are detected at a peak hour intersection: Extra Time = 2 × 5 seconds = 10 seconds New Green Light Time = 40 + 10 = 50 seconds. This ensures that extremely busy roads get proportionally extra time for clearance, allowing unobstructed traffic flow during the day.

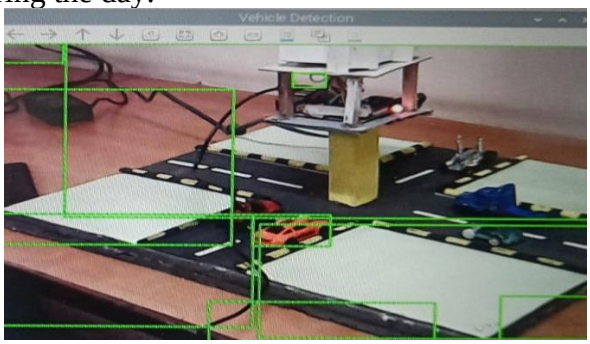

Fig. 9. Vehicles detected by camera

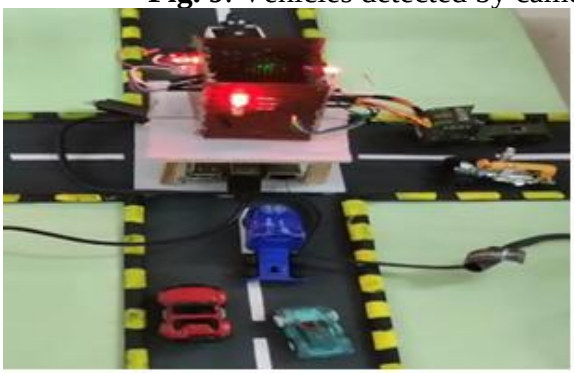

Fig10. Green signal at Road1

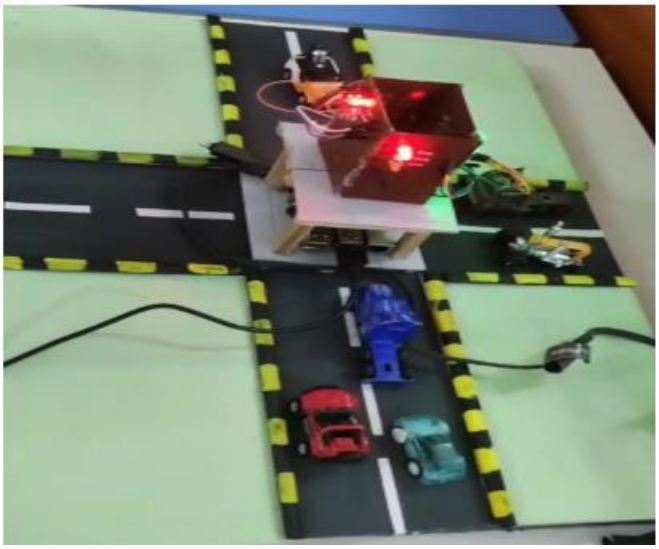

Fig11. Green signal at Road 2

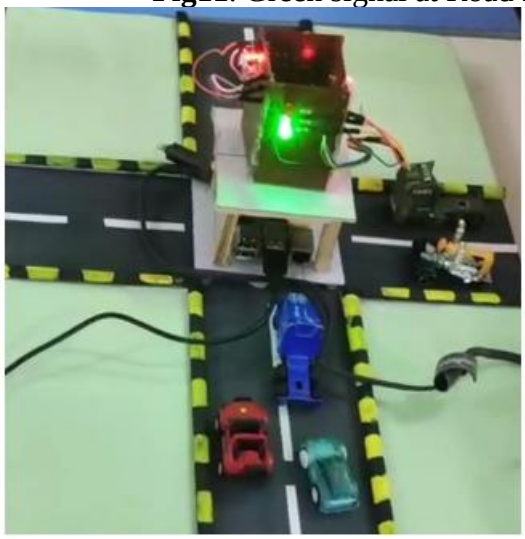

Fig12. Green signal at Road 3

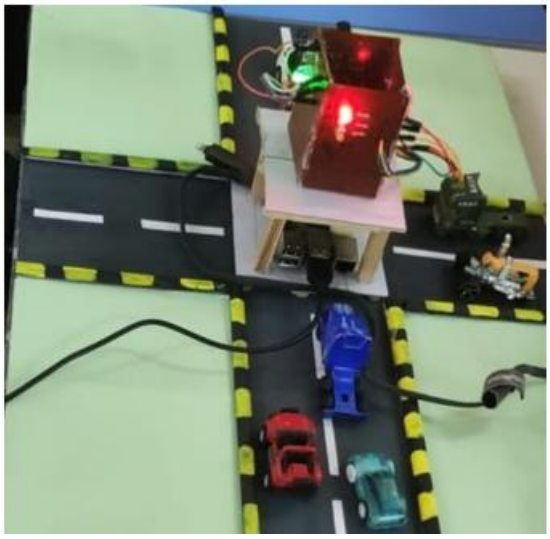

Fig13. Green signal at Road 4

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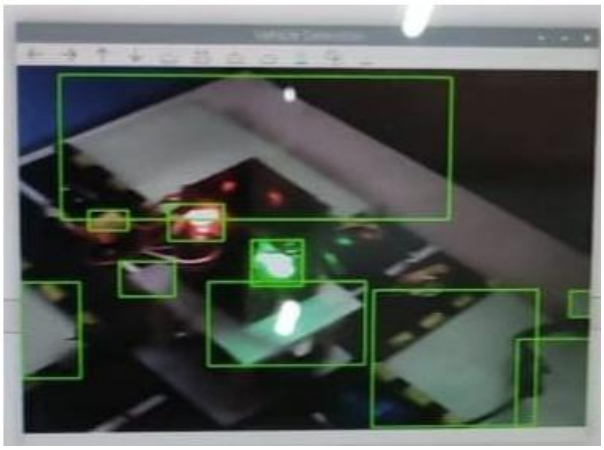

Fig14. Video of Vehicles detected by camera

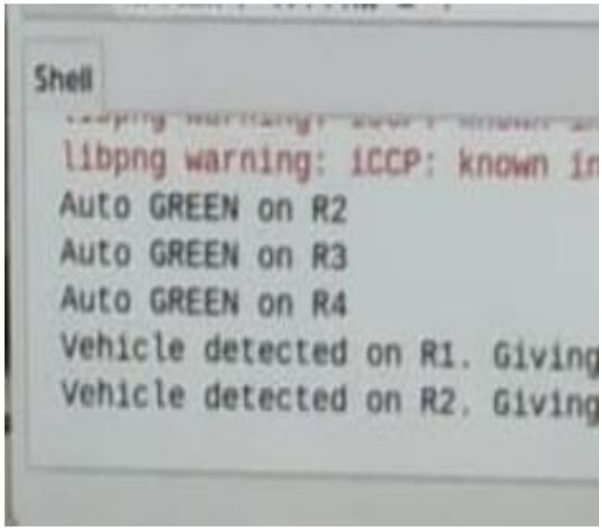

Fig15. Output of vehicle detection

2) User and Admin Web Application for Interaction

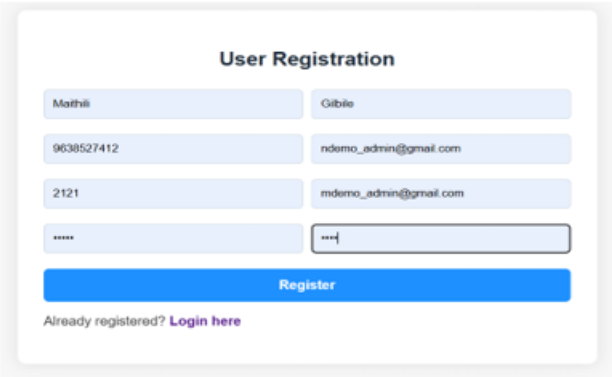

Fig16. User Registeration

This page enables new users to register on the Mumbai Traffic Management portal.Users need to fill in: First Name,Last Name,Mobile Number,Email Address,Vehicle Number,License Number,Password and Confirm Password Basic checks such as password matching and email format validation are done. Once registered successfully, users can log in and use features like complaint filing and traffic alert reporting

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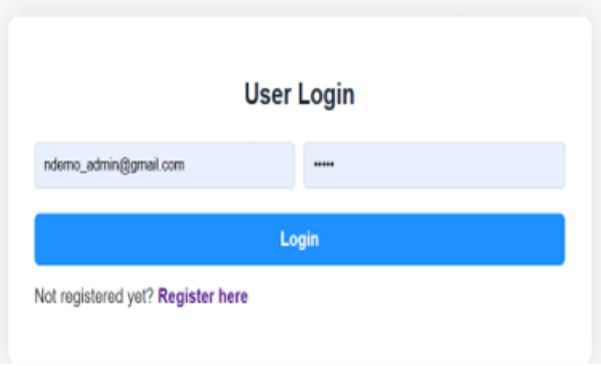

Fig17. User Log-in page
A secure login form for registered users to access complaint submission, report alerts, etc.Offers an option to register if the user does not have an account.

Fig18 User Homepage
The homepage greets users to the Mumbai Traffic Monitoring System. It emphasizes the system's mission with the message: "Stay Safe. Stay Alert. Know the Roads Before You Go." A straightforward button "Check Road Status" enables users to see real-time road conditions instantly.
Under the banner, an "About the Portal" section clearly states the mission — to inform citizens of traffic conditions, traffic alerts, and safety precautions for throughout Mumbai for safer and more efficient journeys.

Fig. 19. User About-Us
Gives an overview of the Mumbai Traffic Management System.Describes the purpose of enhancing road safety and real-time traffic information for the city.Has a visual banner and organized sections regarding the goals and operations of the system.

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Fig20. Saftey and Awerness

Educates users on safe driving practices and road rules.Lists important road safety tips like wearing seatbelts, not using mobile phones while driving, and maintaining safe distances.

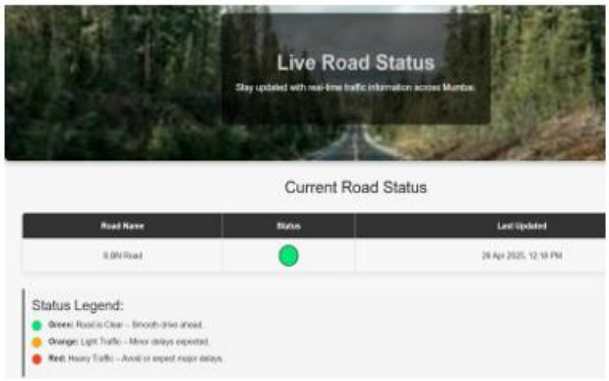

Fig21. Roads and Rules Page

Shows real-time road conditions for various roads in Mumbai. Uses color codes: Green: Clear Road — Yellow: Minor Traffic — Red: Heavy Traffic Displays last updated time and road names.

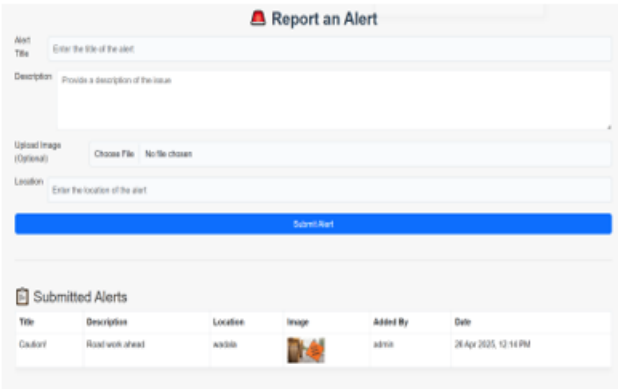

Fig22. Traffic Alert Report Page

Users can report real-time traffic incidents (road work, accidents, jams). Allows uploading an optional image with the alert description and location. Displays a table of previously submitted alerts after admin approval.

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Fig. 23. Complaint Registration Page

Allows users to file complaints regarding traffic issues.Collects details like name, email, contact number, and a message describing the complaint.

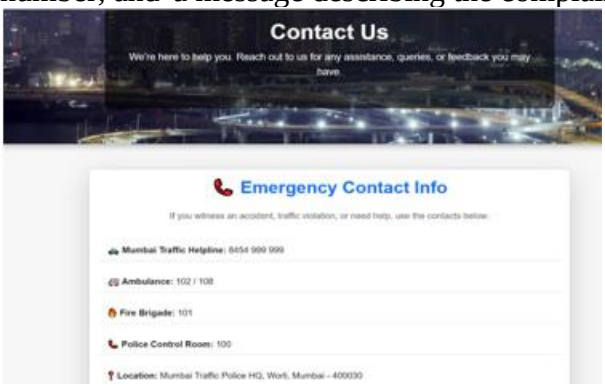

Fig. 24. Contact Page

Displays a list of assigned traffic officers for different roads with their contact numbers.

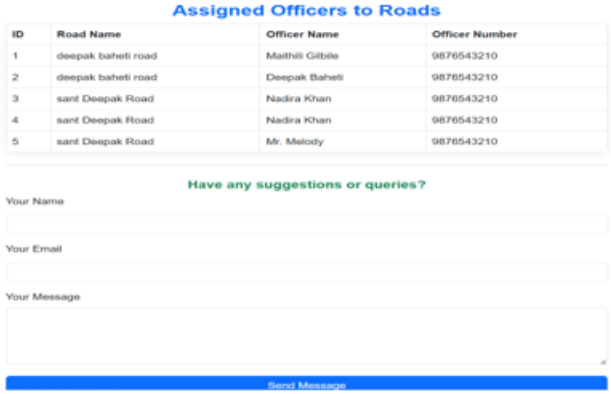

Fig25. Assigned Officers Page

Includes a suggestions or queries form where users can submit their feedback directly to the admin

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2. WEB APPLICATION ACCESSED BY ADMIN

Fig. 26. Admin page dashboard

Takes users to the main landing page where they can view an overview of the portal and access road status updates

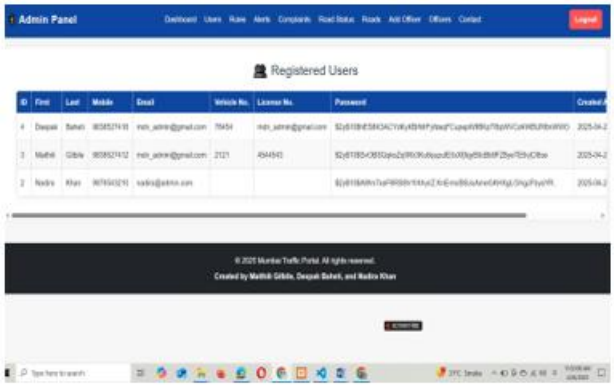

Fig. 27. Registered users page

Options for users to either register for a new account or log in to access complaint submissions and alert reporting features.

Fig. 28. Traffic rules page

Displays important traffic safety guidelines, road rules, and recent updates to ensure responsible driving.

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Fig. 29. Manage traffic rules

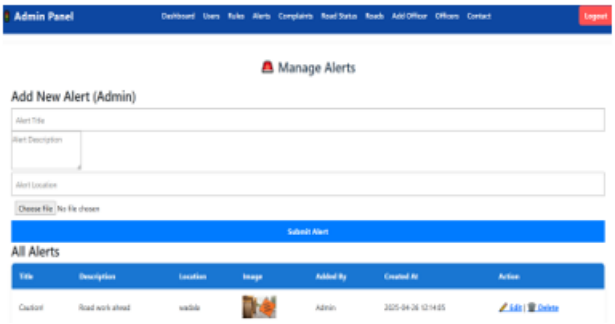

Fig. 30. Manage alert page

Allows users to report incidents like accidents, roadblocks, or heavy traffic by filling a form and uploading images.

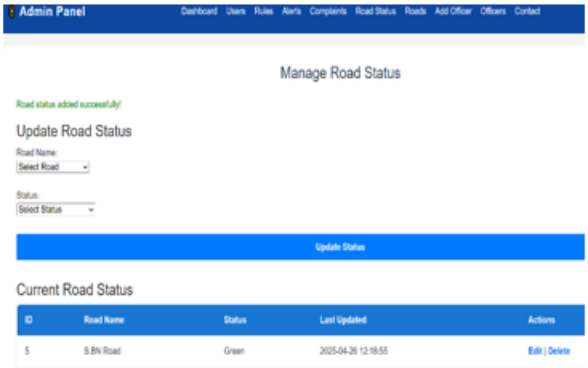

Fig. 31. Manage road status

Shows real-time updates of road conditions across different areas of Mumbai, with a clear traffic status legend (Green, Orange, Red).

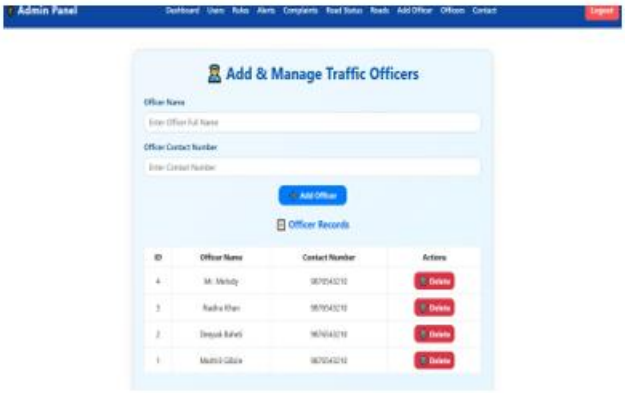

Fig. 32. Add and manage traffic officer

Displays a table showing the list of traffic officers assigned to specific roads, along with their contact

numbers, so that users can directly reach out in case of serious traffic management issues.

Backend of website

Contact us

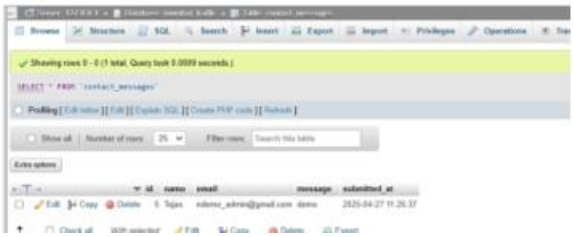

Fig33. Database of contact us

Manage Road status

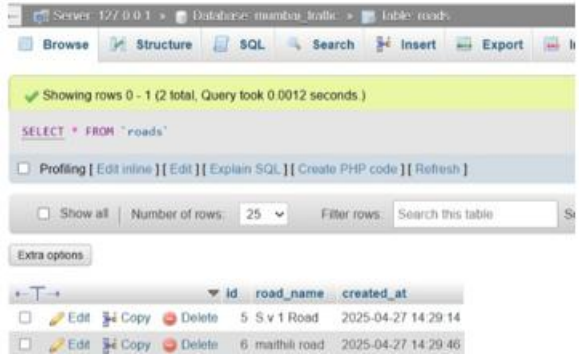

Fig. 34. Database of add/delete status of roads

Manage alerts

Fig. 36. Database of add/delete alerts

Manage traffic officers

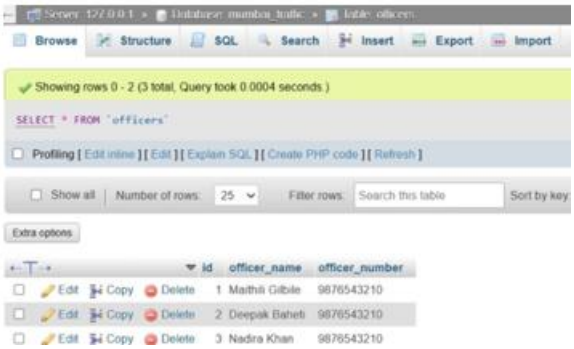

Fig 37. Database of add/manage/delete traffic officers

Future Scope

 Expansion of AI Capabilities: As AI and machine learning evolve, the system can incorporate predictive models to forecast traffic patterns, suggest optimal routes for drivers, and manage congestion in real-time.

• Integration with Smart City Infrastructure: The system can be integrated with other smart city technologies, such as smart parking and environmental monitoring, to create a seamless urban experience.

• Improved User Interaction: Future enhancements could include mobile app integration, voice command features, and more advanced analytics for users to better understand traffic trends and make informed decisions.

• Automated Incident Detection: Using image processing, the system can be trained to automatically detect accidents or unusual events on roads, alerting authorities and users immediately.

• Global Expansion: The system can be expanded to different regions, with localized road data and emergency numbers, creating a global network of smart traffic management systems.

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