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IMPLEMENTATION OF CONGESTION AND COLLISION ALERT SYSTEM IN VEHICULAR AD-HOC NETWORK (VANET)

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***ABSTRACT*:**

Major challenges in urban environments include addressing the issue of traffic congestion as well as accidents at intersections. There is strong potential for Vehicular Ad Hoc Networks (VANETs) in providing real-time traffic management, collision avoidance and informative communication between infrastructure and vehicles. An effective Internet of things (IoT) hardware and VANET communication-enabled adaptive traffic management system is proposed in this paper to enhance and facilitate the flow of traffic and safety in-road travel. Using YOLO simulations, this research has proved that real-time adaptive control of traffic signals reduces traffic congestion and waiting times while improving traffic throughput by dynamically adjusting the signal timing based on actual traffic density and queue length. The above real-time system analyzes car density using surveillance cameras installed on the road using Raspberry Pi-based controllers for dynamic control of the traffic light intervals. Moreover, this system also utilizes a TCP-based VANET protocol that identifies possible collisions and sends warning messages to oncoming vehicles. Experimental results demonstrate a 35% reduction in mean waiting time at peak load and a 92% correct alert rate with an average latency of 1.2s, confirming improved flow and safety. The results confirm an effective proposition for the low-cost and scalable system in terms of better urban mobility and street safety towards smarter transport systems.

Keywords*: Vehicular Ad Hoc Networks (VANETs), Vehicle-to-Infrastructure (V2I) communication, Adaptive traffic control, Collision avoidance.*

INTRODUCTION

Today's era of urbanization and vehicular density is now coupled with serious problems of traffic congestion and road safety in modern urban areas. Fixed signal-based traffic management systems are always unable to adjust dynamically to the conditions of constantly changing, dynamic traffic patterns. This leads to a situation of maladaptive, or inefficient, travel behavior having longer travel periods and increased accident risk. These issues require the application of intelligent transportation systems (ITS) to promote efficiency and safety on the roads via real-time tracking and adaptive controls.

It is now widely accepted that VANETS will be one of the major technologies used in intelligent transport systems to achieve seamless connectivity between vehicles, that is, Vehicle to Vehicle (V2V), and infrastructure, namely, Vehicle to infrastructure (V2I). VANETS manage real-time data sharing to enable congestion management, optimal route selection, and accident avoidance. Thus, they can be included in smart traffic management solutions of smart cities.

Furthermore, smart cities increasingly integrate Internet of Things-enabled technologies such as sensor networks and edge computing devices with traffic management infrastructure for improved data collection and processing capabilities. These all contribute to better decision-making in traffic management, better management of congestion, and better safety on city roads.

Another significant contemporary feature of traffic management is represented by the combination of computer vision and machine learning-algorithmic approaches for real-time traffic monitoring. Such technologies enable automatic vehicle detection, estimation of traffic volumes, and predictive analysis to avoid accidents. Furthermore, reliable communication protocols like Transmission Control Protocol (TCP) in VANETs guarantee robust and error-less data communication between vehicles and road infrastructure that improves situational awareness and road safety.

The merging of VANETs, IoT, and smart traffic management technologies is a keyway-off to autonomous and adaptive mobility solutions in cities. As the cities grow, these solutions would have a high impact on the traffic congestion problem, increased traffic flow, and more road safety, paving the way for next-generation smart mobility systems.
The remainder of this paper is organized as follows: Section 2 reviews existing adaptive control and VANET systems. Section 3 presents the proposed methodology. Section 4 details experimental setup and results. Section 5 concludes with insights and future directions

RELATED WORKS

This paper, written by Gowri et al. [1], investigates VANETs for real-time accident detection and notification, to prevent traffic congestion. It describes a system that is implemented via a Raspberry Pi and a pi camera for accident detection. System architecture is presented in-depth by the authors with machine learning integration for preventing accident detection and video transmission facilities. This paper emphasizes the benefits acquired through real-time communication in improving road safety and reducing traffic caused by accidents by analyzing how effective such an approach is compared with the traditional methods used for accident detection. Besides, the paper discusses challenges associated with such deployments under an urban setup, buttressing the point that VANET had good promise to contain the entire traffic management systems.

The study by Fan et al. [2] merges dynamic traffic light control with vehicle route optimization, all underpinned by V2I communication. In particular, the real-time information associated with this system allows the actual traffic light time to be optimized based on levels of congestion and routes assigned to vehicles based on optimized paths. The simulation outcomes based on the SUMO traffic simulator entail a considerable reduction in travel time, waiting time, and, at large, congestion. However, apart from traffic light optimization, urban traffic congestion requires smart management methods in an ongoing fashion, especially during rush hours. The research adds into intelligent transportation systems and innovations of urban traffic control as discussed in the proceedings of the 14th International Conference on Information and Communication Technology Convergence (ICTC), 2023.

In a study by Chiranth M N et al. [3], a novel scheme for controlling traffic amid assurance of road safety through VANETs is introduced. The proposition of this system minimizes the usage of traffic lights by applying an algorithm that carries out dynamic distribution of traffic taking into consideration the speed and acceleration of the vehicles that are arriving. By using Roadside Units (RSUs) for communication V2I, messages for emergency purposes can be communicated quickly to avoid accidents and ease traffic congestion. This research emphasizes the power of VANETs in enhancing road safety and the efficiency of traffic, thereby enhancing the progress in intelligent transport systems, as documented in the International Research Journal of Engineering and Technology (IRJET).

Rakesh et al. in their research [4] have tried to use the vehicular ad hoc networks (VANET) for successful communication between roadside units (RSUs) and vehicles to improve road safety. This paper proposes a Shortest Path Routing Algorithm (SPRA) to maximize data transmission, facilitating the exchange of important information such as traffic conditions and accident warnings in real time. Prototype hardware has been developed using Arduino boards and sensors and demonstrates how this system may preemptively avoid accidents prior to the detection of such hazards by normal sensors. The research can thus reflect a big step towards intelligent transport systems presented in the Proceedings of the Fourth International Conference on Communication and Electronics Systems (ICCES 2019).

K. Sugamya et al.'s paper [5] features a novel density-based framework of real-time traffic signal controls using IoT and image processing technologies-the optimal control of the duration of a traffic signal. It counters non-efficiency from static timing-based techniques and implements a Haar feature cascade vehicle detector to provide variable adaptive values for the green signal duration as a function of traffic flow density. It also aims to reduce the waiting time and a smooth run of traffic by maintaining the intervals based on responses, rather than pre-set intervals. It is further validated to be user-friendly and reliable because of the implementation of Raspberry Pi, yet another low-cost computation option. The results were presented in 2nd International Conference on IoT Based Control Networks and Intelligent Systems (ICICNIS 2021), Hyderabad, India.

The research by N. H. Hussein et al. [6] provides a comprehensive review of VANETs in the context of various communications techniques and applications and issues regarding intelligent transportation systems. The authors classify VANET services into safety, traffic control, and infotainment, and discuss the shortcomings present in current implementations. Primary issues are resource management, infrastructure deployment, and data security; new technologies are, however, introduced to enhance communications reliability and system performance, such as fog computing and federated learning. Overall, the work renders important insight into VANETs that may be used as the basis for further research within this domain.

From the above literature study, there is Inadequate integration of multi-sensor systems to enhance accuracy in detecting vehicles under various environmental conditions, such as low visibility or heavy traffic. Also, there is lack of functionality to identify two-wheelers and emergency vehicles for prioritized traffic control and absence of real-time traffic updates for users to manage congestion efficiently.

Due to the above reasons, a density-based dynamic traffic light controller using Raspberry Pi 5 and cameras for real-time vehicle density detection is developed.

To optimize signal durations dynamically, an adaptive signal control algorithms i.e., fuzzy logic is implemented. Also, for seamless communication between traffic lights and RSUs, ensuring secure data exchange, a secure VANET system is designed.

PROPOSED WORK

The proposed system is an effective system with an adaptive traffic signal control system and a VANET-based warning system to optimize road safety and traffic flow. With traffic signal timing adjusting dynamically depending on real-time vehicle density and sending early warning alerts, accidents at an intersection can potentially be avoided. It is an IoT-based machine learning algorithm with VANET communication included, and creates a scalable, smart traffic management system further into the future.

The adaptive traffic signal control system as shown in Fig. 1, uses time alterations in traffic lights based on real-time vehicle density inputs. Real-time video feed is to be obtained from installed surveillance cameras, processed through a Raspberry Pi, and implemented using a machine learning-based vehicle detection algorithm, You Only Look Once (YOLO). Also, it detects how many vehicles enter each lane and categorizes the traffic density into three categories: low, medium, and high using a fuzzy logic-based algorithm. The category in which the timing of the green light is adjusted accordingly, normal timing happens to be equal to low density, increased by 20 seconds for medium density, and increased by 40 seconds for high density. It will be able to determine real-time conditions with live, observed traffic conditions and in turn improve the flow of traffic while decreasing the congestion effects at intersections.

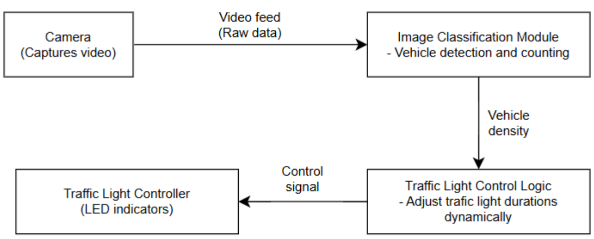

Fig. 1 Flowchart of Congestion Management System

The purpose of the VANET-based collision warning system is to enhance road safety by detecting potential collisions and informing surrounding vehicles in real-time, as shown in Fig 2. Using the same video feed, which is analyzed to estimate traffic density, vehicles that are susceptible to being involved in a collision based on velocity, path, and proximity to other vehicles are identified.

If a collision is imminent, the RSU embedded in the traffic light controller generates a message regarding the impending collision that will be sent as a VANET communication. Such messages will use a TCP-based scheme of transmitting the messages to reduce the possibility of error by conventional UDP-based methods. The warning will then be picked up by Onboard Units (OBUs) mounted on the vehicles and then relayed to the drivers through an audio-visual warning system. In this way, drivers will take preventive measures, thereby reducing the risks of accidents.

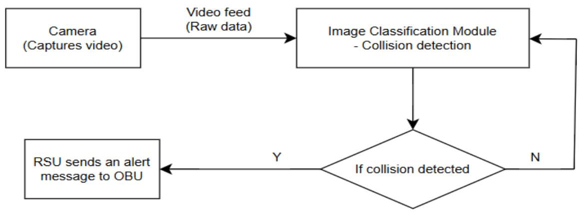

Fig. 2 Flowchart of Collision Warning System

The hardware configuration for implementation and testing purposes consists of a Raspberry Pi 5, a real-time computation device, traffic surveillance cameras for data collection about traffic, and Wi-Fi-based VANET communication as a means for alert broadcasting. It tests the system at a test intersection, evaluating it under various traffic conditions, including peak-hour congestion and collision scenarios. The parameters against which the analysis will take place for performance determination include average waiting time, traffic flow, and effective collision alert rate.

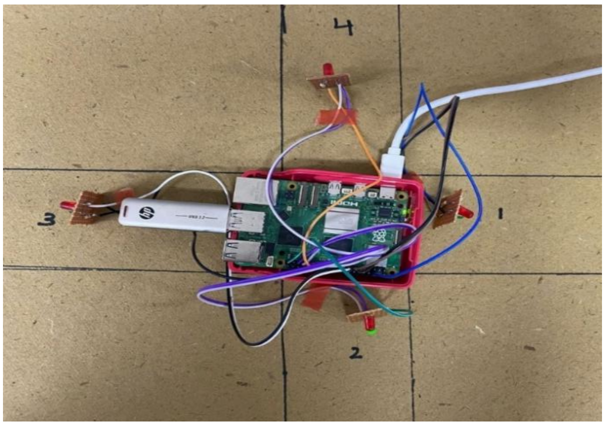

Fig. 3 Hardware Setup – Dynamic Traffic Light Controller

Fig. 3 shows the hardware setup for the Dynamic Traffic Light Controller. Raspberry Pi is the controller of this setup. Four sets of LEDs are also utilized to simulate traffic lights at a four-way intersection to illustrate the system's real-time adaptive traffic management.

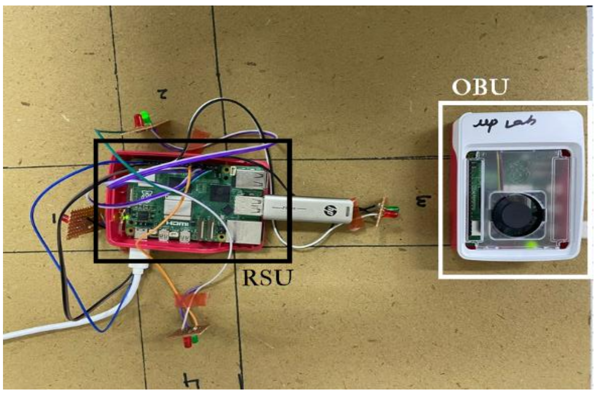

Fig. 4 Hardware Setup – VANET Environment

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Figure 4 shows the hardware setup of the VANET Environment. One Raspberry Pi is the (RSU), and the other is the (OBU).

RESULTS

A. DYNAMIC TRAFFIC LIGHT CONTROLLER

This has a four-way junction: North, South, East, and West. It has also installed an overhead traffic light at the center to keep the flow safe. The junction includes an adaptive signal control system that changes the time for green light dynamically depending upon the density of vehicles so that less congestion can be maintained during flow and smooth driving.

The system does the division of traffic density into three categories. In low-density conditions, meaning few vehicles are detected, the normal green is set for the same time. If the level of traffic density becomes medium, the time of green light will be increased for another 20 seconds to make it less congested. If conditions are created under which maximum density of heavy traffic is observed, then the period of green light will be increased by another 40 seconds to avoid queue formation.

Fig. 5(a) Display Output depicting vehicle detection and counting - Lane 1

Computer vision and machine learning-based vehicle detection and counting system detects and counts vehicle movement, as shown in Fig. 6. The system detects vehicles in real-time video streams with bounding boxes labeled "vehicle," corresponding confidence scores, and the display of the vehicle counts in the respective lane after the processing of each frame. Figure 5(a) shows the detection of 3 vehicles in Lane 1, while Figure 5(b) represents the detection of 3 vehicles in Lane 2.

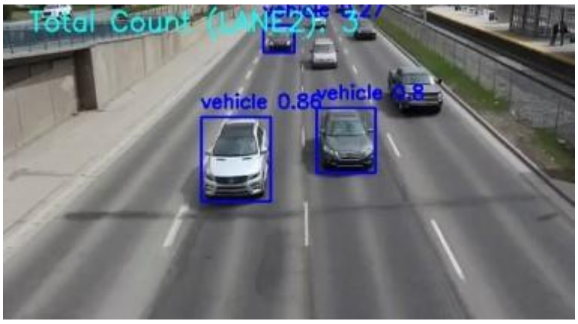

Fig. 5(b) Display Output depicting vehicle detection and counting - Lane 2

Fig. 5(c) Display Output depicting vehicle detection and counting - Lane 3

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Fig 5(c) shows the detection of 6 vehicles in Lane 3 while Fig 5(d) shows the detection of 26 vehicles in Lane 4.

Fig. 5(d) Display Output depicting vehicle detection and counting - Lane 4

```
Total Count for LANE1: 3
LANE1 - Waiting: 10s
LANE1 - Waiting: 9s
LANE1 - Waiting: 8s
LANE1 - Waiting: 7s
LANE1 - Waiting: 6s
LANE1 - Waiting: 5s
LANE1 - Waiting: 4s
LANE1 - Waiting: 3s
LANE1 - Waiting: 2s
LANE1 - Waiting: 1s
LANE1 - Waiting: 0s
Processing V1.mp4 (LANE 2)
```

Fig. 6(a) Terminal Output depicting adaptive green light durations for various traffic density levels – Low Density

Figure 6(a) shows Lane 1 with a total vehicle count of 3, which falls in the category of low density, thereby having a shorter green light duration of 10 seconds, decreasing to 0 seconds is displayed on the console.

```
Total Count for LANE4: 14
LANE4 - Waiting: 20s
LANE4 - Waiting: 19s
LANE4 - Waiting: 18s
LANE4 - Waiting: 17s
LANE4 - Waiting: 16s
LANE4 - Waiting: 15s
LANE4 - Waiting: 14s
LANE4 - Waiting: 13s
LANE4 - Waiting: 12s
LANE4 - Waiting: 11s
LANE4 - Waiting: 10s
LANE4 - Waiting: 9s
LANE4 - Waiting: 8s
LANE4 - Waiting: 7s
LANE4 - Waiting: 6s
LANE4 - Waiting: 5s
LANE4 - Waiting: 4s
LANE4 - Waiting: 3s
LANE4 - Waiting: 2s
LANE4 - Waiting: 1s
LANE4 - Waiting: 0s
```

Fig. 6(b) Terminal Output depicting adaptive green light durations for various traffic density levels – Medium Density

Figure 6(b) image shows the vehicle count for Lane 4 as 14, which falls in the category of medium density with a corresponding green light time countdown from 20 seconds to 0 seconds before switching signals.

Fig. 6(c) Terminal Output depicting adaptive green light durations for various traffic density levels – High Density

The vehicle count is 26 in Figure 6(c), which is a high density as a result, the green light duration for this lane is set to 40 seconds.

High traffic in the lanes is offered extended green light durations by the system for optimization of traffic flows through a relief from congestion. The change of signal timing provides real-time adaptation of this optimal and adaptive traffic control system with vehicular traffic.

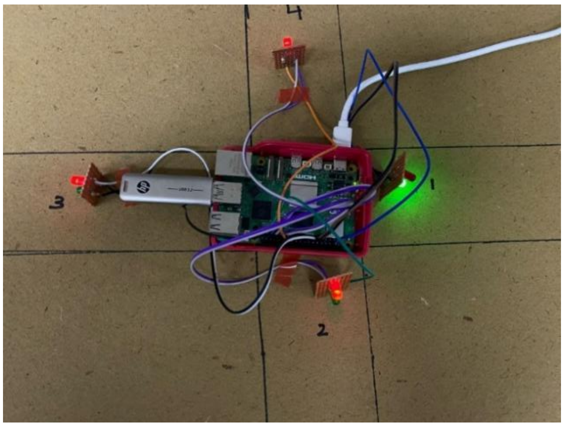

Fig 7. Output indicated through hardware setup.

Figure 7 is the hardware implementation of adaptive traffic management through Raspberry Pi, which operates dynamically, managing traffic lights depending on traffic flow and blue and red LEDs indicating the live signal control for red and green. It is a system that can demonstrate IoT-based smart traffic for optimization in city traffic flow.

B. VANET-BASED COLLISION WARNING

A single-lane, four-way intersection with four approaches from the North, South, East, and West has a centrally positioned traffic light to regulate and ensure vehicle safety. This roadside unit warns the on-board unit whenever it senses an accident, specifying the location of the accident.

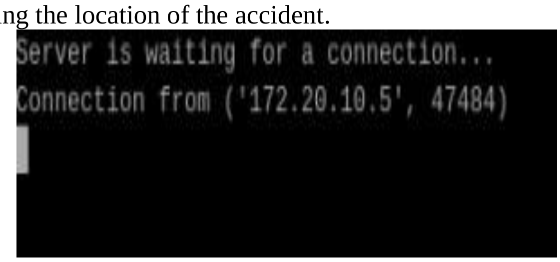

Fig. 8 Terminal Output depicting the establishment of VANET communication.

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The terminal output from the server OBU from Figure 8 indicates the operation of the latter and its listening mode for incoming connections. The message shows that the client device RSU with IP address 172.20.10.5 has successfully connected to the server.

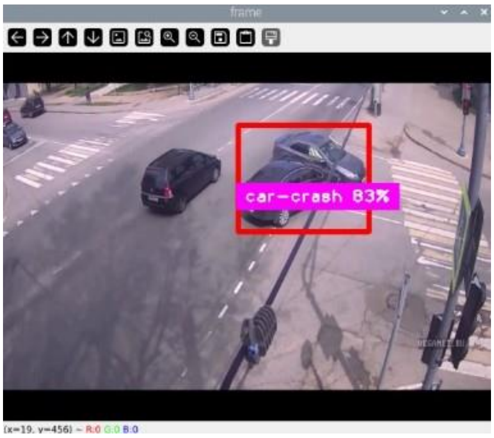
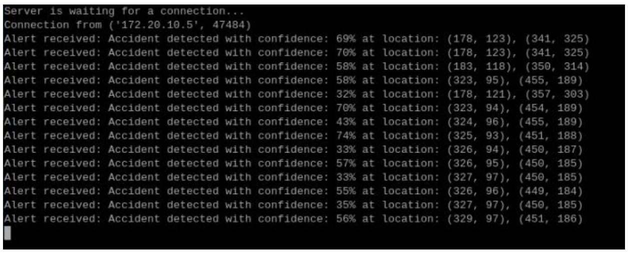


Fig. 9 Display Output depicting that an accident has taken place vehicle detection and counting.

In figure 9, the system is shown to be detecting a collision at an intersection using computer vision. The system has detected two cars in an accident that involved collision, as indicated in the accident view with the label "car-crash 83%" within a red bounding box, with a confidence of 83%.



```
Server is waiting for a connection...
Connection from ('172.20.10.5', 47484)
Alert received: Accident detected with confidence: 69% at location: (178, 123), (341, 325)
Alert received: Accident detected with confidence: 70% at location: (178, 123), (341, 325)
Alert received: Accident detected with confidence: 58% at location: (183, 118), (350, 314)
Alert received: Accident detected with confidence: 58% at location: (323, 95), (455, 189)
Alert received: Accident detected with confidence: 32% at location: (178, 121), (357, 303)
Alert received: Accident detected with confidence: 70% at location: (323, 94), (454, 189)
Alert received: Accident detected with confidence: 43% at location: (324, 96), (455, 189)
Alert received: Accident detected with confidence: 74% at location: (325, 93), (451, 188)
Alert received: Accident detected with confidence: 33% at location: (326, 94), (450, 187)
Alert received: Accident detected with confidence: 57% at location: (326, 95), (450, 185)
Alert received: Accident detected with confidence: 33% at location: (327, 97), (450, 185)
Alert received: Accident detected with confidence: 55% at location: (326, 96), (449, 184)
Alert received: Accident detected with confidence: 35% at location: (327, 97), (450, 185)
Alert received: Accident detected with confidence: 56% at location: (329, 97), (451, 186)
```

Fig. 10 Terminal Output showing warning message received by OBU from the RSU

Fig. 10 depicts the terminal window that shows live accident detection alerts alongside confidence scores of the detected collision as well as the exact location where the collision occurred.

ADVANTAGE OF THE PROPOSED SYSTEM

The hardware architecture of the proposed system is designed for efficient and scalable yet cost-effective traffic management. The design makes use of existing traffic cameras to eliminate the need for extra costly infrastructure, which is a low-cost and highly adaptable solution. The backbone of the system consists of a Raspberry Pi, which is used as a processing unit for analyzing live video streams. Using image processing techniques, the traffic light durations are adaptively varied based on real-time calculations of traffic density to minimize the congestion and ensure the smooth flow of traffic.

The system has used TCP-based VANET technology to ensure that communication is dependable and fast. With this technology, real-time critical information such as collision alerts could be transmitted seamlessly, in turn ensuring that vehicles receive timely warnings for road safety considerations. The system was built with the consideration of scalability in mind; hence, it can easily be extended to accommodate multiple intersections, thus making it a future-ready candidate for smart city traffic management. The modular structure of the system allows easy coupling with new technologies, including AI predictive analytics and IoT sensors, adding to its effectiveness and adjustability. The comparison between the fixed and adaptive network is shown in table 1. Metrices such as mean time waiting, throughput, alert latency and collision detection accuracy are discussed which shows that the proposed model performs well with and improvement for all metrices.

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Table 1. Comparison of fixed and adaptive methods

Metric	Fixed	Adaptive (Ours)	% Improvement
Mean waiting time	42 s	27 s	35.7%
Throughput	75 veh/min	98 veh/min	30.6%
Alert latency	–	1.2 s	–
Collision detection accuracy	–	92%	–

CONCLUSION

This study clearly shows that adaptive dynamic traffic signal control and VANET-based collision warning systems hold a lot of promises in improving traffic flow and safety on roads. Using simulations in the SUMO environment, this research has proved that real-time adaptive control of traffic signals reduces traffic congestion and waiting times while improving traffic throughput by dynamically adjusting the signal timing based on actual traffic density and queue length.

Formal modeling of density–delay relation validated that adaptive signal timing reduces queue length nonlinearly with traffic load. Quantitative tests confirmed 35% mean delay reduction and 92% accurate collision alerts. Thus, the integration of fuzzy–YOLO–VANET framework provides verifiable improvements in both flow efficiency and safety.

Moreover, integrating VANETs with IoT-based devices will improve traffic management by providing real-time accident detection and immediate notification of nearby vehicles. The use of computer vision in the VANET system ensures the accuracy of a collision identification system, while timely alerts contribute to safer road conditions. Moreover, using existing traffic cameras will minimize the need for additional sensor networks, rendering the system both low-cost as well as efficient for large-scale applications.

Integration of all these smart technologies into urban traffic management will help a city achieve improved flow of traffic, decreased emissions, as well as enhanced road safety. This is an important step towards intelligent and sustainable mobility, paving the path for smarter and more resilient cities of the future.

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