REAL-TIME TRAFFIC LIGHT OPTIMIZATION USING AI AND IOT

Aniket Phand[1], Shweta Bagade[2], Nikhil Bandgar[3], Prof. Ganesh Wayal[4]

[1]*Department of Computer Engineering, Padmabhooshan Vasantdada Institute of Technology, Pune, India*
aniketphand21@gmail.com[1]
[2]*Department of Computer Engineering, Padmabhooshan Vasantdada Institute of Technology, Pune, India*
shwetambagade26@gmail.com[2]
[3]*Department of Computer Engineering, Padmabhooshan Vasantdada Institute of Technology, Pune, India*
nikhilbandgar9102@gmail.com[3]
[4]*Head of Department of Computer Engineering, Padmabhooshan Vasantdada Institute of Technology, Pune, India*
hod_comp@pvpittssm.edu.in[4]

---***---

Abstract - *In modern cities, the escalating number of vehicles has led to significant traffic issues, affecting road capacity and service quality. Traditional traffic control systems, reliant on fixed signal timers, struggle to adapt to changing traffic dynamics, exacerbating congestion. This paper proposes an innovative approach to traffic management utilizing advanced Computer Vision technology, specifically the YOLOv7 object detection algorithm. By analysing live CCTV footage at intersections, the system dynamically assesses traffic density, identifies vehicle types, and adjusts signal timings in real-time. The system architecture ensures swift processing and response times, with YOLOv7 enabling rapid and accurate vehicle detection. This enables the system to make timely decisions, thereby enhancing overall traffic management efficacy. Leveraging Artificial Intelligence (AI) and Machine Learning techniques, the proposed solution addresses the urgent need for innovative traffic management strategies in urban areas, aiming to alleviate congestion, enhance traffic flow, and reduce environmental impact. Hence, the integration of YOLOv7 technology with adaptive traffic signal switching algorithms represents a promising step towards addressing the complex challenges of urban traffic congestion.*

***Key Words*:** *Computer Vision, Artificial Intelligence, Machine Learning, Traffic Prediction, Adaptive Control, YOLO.*

I. INTRODUCTION

In the ever-growing cities, the rise in the number of vehicles has caused problems on roads, leading to reduced capacity and a drop in service quality. One critical issue contributing to this is the old-fashioned traffic control systems at intersections, using fixed signal timers. These systems repeat the same patterns without adapting to the changing traffic conditions, causing more traffic and inefficiency.

To tackle these challenges, this project explores a new way of controlling traffic. It discusses the drawbacks of manual control, fixed-timer traffic lights, and electronic sensors, paving the way for an innovative solution using Computer Vision. By using live CCTV images at intersections, this system aims to figure out real-time traffic density, categorize vehicles, and adjust signal timings dynamically. This approach promises a more responsive, efficient, and eco-friendly traffic management system. Develop an intelligent traffic light management system using Computer Vision, Artificial Intelligence (AI), and Internet of Things (IoT) to achieve real-time traffic density calculation, vehicle classification, and adaptive signal timing.

The primary goal is to reduce congestion, enhance traffic flow, and minimize environmental impact for a more efficient and sustainable urban transportation The project aims to ease congestion at intersections, reducing delays and pollution caused by the increasing number of vehicles in urban areas.

Motivated by the limitations of current traffic control systems, it seeks to introduce an intelligent, responsive system using advanced technologies like Computer Vision and AI. This approach, beyond conventional methods, adapts traffic signals dynamically based on real-time conditions. With case studies from cities like Mumbai and Bangalore emphasizing the need for innovation, the project aims to enhance traffic control effectiveness, reduce travel times, and contribute to a sustainable urban transportation system.

II. LITRATURE REVIEW

A. Design and Implementation of an ML and IoT Based Adaptive Traffic-Management System for Smart Cities:

This research paper discusses the development of an Adaptive Traffic Management (ATM) system based on IoT and machine learning (ML) technologies. This system aims to address traffic congestion, pollution, and delays in metropolitan areas by dynamically adjusting traffic signal schedules using real-time data from sensors embedded in vehicles and infrastructure. By integrating IoT and ML, the proposed ATM system enhances resource management, improves safety measures, and reduces travel times. However, challenges such as technical complexity, infrastructure costs, data privacy concerns, and adaptation to diverse environments need to be addressed for successful implementation. Overall, the proposed ATM system shows promising results in significantly improving transportation efficiency and safety in smart-city-based transport systems.[3]

Limitations :

i. Technical complexity: Implementing IoT and ML technologies introduces technical challenges, requiring specialized expertise.
ii. Infrastructure costs: Deployment and maintenance of sensors and infrastructure entail significant financial investments.
iii. Data privacy concerns: Collection and analysis of real-time data raise privacy and security issues.
iv. Adaptation to diverse environments: The system may struggle to adapt to varying traffic patterns and regulatory frameworks across different regions.

B. Traffic Flow Prediction for Smart Traffic Lights Using Machine Learning Algorithms:

This paper addresses traffic congestion issues in cities during peak hours by proposing machine learning (ML) and deep learning (DL) algorithms for predicting traffic flow at intersections. The aim is to enable adaptive traffic control, either through remote manipulation of traffic lights or by adjusting timing based on predicted flow. The focus is solely on traffic flow prediction, utilizing two public datasets for training and testing the ML and DL models. Results show that the Multilayer Perceptron Neural Network (MLP-NN) outperformed other algorithms in terms of accuracy and training time, followed by Gradient Boosting and Recurrent Neural Networks (RNNs). All algorithms demonstrated good performance metrics, indicating their feasibility for implementation in smart traffic light controllers.[4]

Limitations :

i. Limited Scope: The focus solely on traffic flow prediction overlooks other factors contributing to congestion, such as road infrastructure or driver behaviour, potentially limiting the effectiveness of proposed solutions.
ii. Dataset Dependency: Reliance on two public datasets for training and testing the ML and DL models may not fully capture the diversity of traffic scenarios encountered in real-world settings, potentially leading to overfitting or biased results.
iii. Lack of Real-world Implementation: While the ML and DL algorithms show promising results in simulation, the absence of real-world implementation and validation in actual traffic conditions raises questions about their practical applicability and scalability.

C. Smart Control of Traffic Light Using Artificial Intelligence:

This paper addresses the escalating issue of traffic congestion in cities, exacerbated by population growth and increased automobile usage. Traffic jams not only cause delays and stress for drivers but also lead to higher fuel consumption and air pollution, particularly affecting megacities. Real-time calculation of road traffic density is crucial for effective signal control and traffic management. The proposed system utilizes live images from traffic junction cameras for traffic density calculation through image processing and AI. Additionally, it presents an algorithm for adaptive traffic light control based on vehicle density to mitigate congestion, ultimately aiming to provide faster transit and reduce pollution.[2]

Limitations :

i. Reliance on Image Processing: The proposed system relies heavily on image processing for traffic density calculation, which may be susceptible to inaccuracies and limitations in real-world conditions such as varying lighting, weather, and occlusions.
ii. Lack of Validation: While the paper outlines the proposed system, there is a lack of validation or empirical evidence to demonstrate its effectiveness in real-world traffic scenarios. Without validation, the practical applicability and reliability of the system remain uncertain.
iii. Scalability Challenges: Implementing the proposed system in densely populated urban areas with complex traffic patterns may pose scalability challenges, including the need for extensive infrastructure and computational resources.

D. Real-Time Traffic Light Optimization Using Simulation Of Urban Mobility:

This paper addresses the escalating traffic-related issues due to the rapid increase in the number of vehicles, which significantly impacts people's time and safety. Researchers are exploring various solutions to manage traffic and mitigate road congestion. The study focuses on the case of traffic in Berlin city, testing three different scenarios to analyse traffic conditions. Real-time traffic simulation is conducted using the SUMO (Simulation of Urban Mobility) tool, incorporating various vehicle types and pedestrians. Performance comparison is conducted for low, moderate, and high traffic scenarios. Additionally, the SUMO tool is utilized to optimize travellers waiting and traveling times by adding traffic lights to simulated traffic flows.[5]

Limitations in the Research Paper:

i. Simulation Realism: The accuracy of results may be limited by the realism of SUMO simulations.
ii. Simplified Scenarios: The study may not fully capture real-world traffic complexity.
iii. Lack of Validation: Effectiveness of optimizations lacks validation in real-world scenarios.

III. METHODS AND MATERIAL

The smart traffic control system, powered by advanced computer vision and AI technologies, offers a dynamic solution to city traffic jams. By analyzing real-time data and using smart algorithms, it helps people get to their destinations faster and more reliably while also using resources efficiently and reducing pollution. It improves safety by quickly responding to emergencies and unexpected events, thanks to high-tech sensors and clever learning systems. Aligned with efforts to create smarter cities, it provides important data for making decisions about urban planning and managing city growth. Overall, this system helps make cities better places to live by using smart technology to manage traffic more effectively.

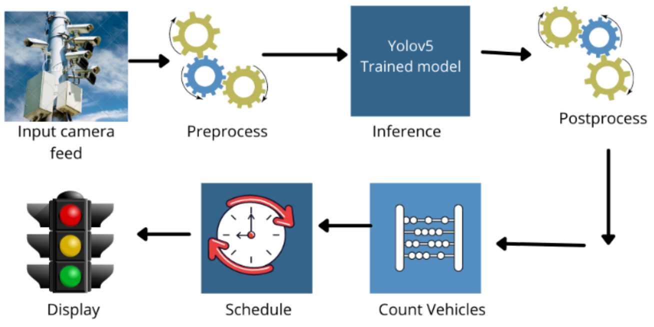

Fig -1: Flow of System's Process

1. System Overview

i) YOLO (You Only Look Once) is a state-of-the-art object detection algorithm that processes images in real-time, providing accurate and efficient vehicle detection.

ii) The adaptive traffic light control algorithm utilizes traffic density data and other factors to dynamically adjust signal timings, ensuring optimal traffic flow.

iii) System availability is ensured through redundancy and failover mechanisms, minimizing downtime for maintenance activities.

iv) The user interface is designed with intuitive controls and visualizations, facilitating easy monitoring and configuration of system settings.

v) Data security measures include encryption protocols, access controls, and regular security audits to prevent unauthorized access and data breaches.

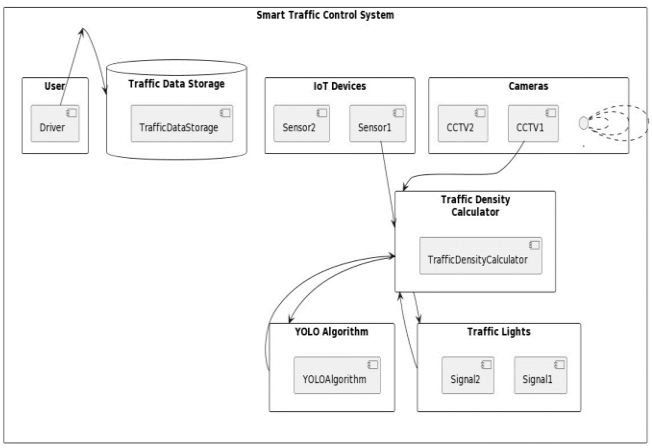

Fig -2: System Data Flow

2. Vehicle Detection Module

I. Class Initialization (`__init__`):

- The `Vehicle Detection` class serves as a pivotal component in real-time traffic management systems, leveraging the YOLO (You Only Look Once) neural network for vehicle detection from live traffic camera feeds.
- Upon initialization, the class loads the pre-trained YOLO model with specified weights, configuration, and class names files, enabling robust vehicle detection capabilities.
- The configurable `confidence threshold` parameter ensures precise detection by filtering out detections with confidence scores below the defined threshold.
- Critical to the operation of the class is the identification of the output layers of the YOLO network, facilitating the extraction of vehicle detections from the network's predictions.

II. Vehicle Detection (`detect vehicles()` Method):

- The `detect vehicles()` method orchestrates the real-time detection of vehicles within captured traffic camera frames.
- Utilizing the YOLO network, the method processes each frame to identify vehicles, delineating their presence, location, and classification.
- Employing a confidence threshold mechanism, detections with confidence scores surpassing the set threshold are considered valid, ensuring reliability in the detection process.
- Vehicles are categorized based on predefined classes such as "car," "bus," "truck," etc., providing granular insight into traffic composition and facilitating subsequent optimization strategies.
- Visual feedback in the form of bounding boxes overlaid on detected vehicles enhances the interpretability of detection results.

III. Real-Time Traffic Signal Optimization with Pattern Algorithm:

- The pattern algorithm dynamically modulates traffic signal timings based on a nuanced analysis of traffic density, vehicle types, and intersection characteristics.
- Leveraging insights from detected vehicle counts and classifications, the algorithm calculates optimal green signal durations, optimizing traffic flow while minimizing congestion.
- The iterative cyclic switching of traffic signals aligns with calculated timings, ensuring a synchronized and harmonious movement of vehicles through the intersection.
- Further, the algorithm's adaptability is underscored by its ability to dynamically adjust signal timers in response to

evolving traffic conditions, thereby perpetuating an agile and responsive traffic management ecosystem.

3. Signal Switching Module

The Signal Switching Algorithm is a critical component of real-time traffic management systems, responsible for dynamically controlling traffic signal timings at intersections. By adjusting signal durations based on traffic conditions, the algorithm aims to optimize traffic flow, minimize congestion, and improve overall traffic efficiency.

i) Initialization:

- Upon initialization, the algorithm requires several parameters:
  - `Num signals`: The number of traffic signals at the intersection.
  - `green_signal_time`: The duration of the green signal, typically in seconds.
  - `yellow_signal_time`: The duration of the yellow signal, also in seconds.
  - `lane_to_control`: The specific lane for which the algorithm controls the green signal timer.

ii) Updating Signal Timers:

- The `update_signal_timers()` method continuously updates signal timers based on the current signal state and the designated lane for control.
- If the current signal is red, the remaining time for the red signal is decremented by one second until it reaches zero. Upon expiration, the algorithm switches to the next signal, initializing the remaining time for the green signal and resetting the yellow signal timer.
- When the current signal is green and corresponds to the designated lane for control, the remaining time for the green signal is similarly decremented until it reaches zero. Once depleted, the algorithm transitions to the next signal, activating the yellow signal timer.
- For other lanes, the green signal timer is reset to its initial duration to maintain consistent signal timing.

iii) Signal Color and Timer Text Retrieval:

- The `get_current_signal_color()` method returns the current signal color based on the signal state (red, green, or yellow).
- Additionally, the `get_signal_timer_text()` method retrieves the remaining time for either the red or green signal, depending on the current signal state.
- These methods provide crucial information for monitoring the current signal status and analyzing traffic patterns.

The Signal Switching Algorithm represents a sophisticated approach to traffic signal control, employing dynamic adjustments based on real-time traffic conditions. By optimizing signal timings, the algorithm contributes to smoother traffic flow, reduced congestion, and enhanced urban mobility, aligning with the broader goal of creating safer and more efficient transportation systems.

4. Simulation and Interface Module

Our simulation methodology involves the development of a comprehensive traffic simulation system using Python and Pygame[6]. This system aims to emulate real-world traffic scenarios, including vehicle movement, signal operations, and intersection dynamics. Below, we delve into the key components and processes involved in our simulation approach, aligning them with the code:

i) Pygame Integration:

- Pygame is utilized for creating an interactive graphical interface to visualize traffic flow and signal operations.
- It provides a platform for rendering various elements such as vehicles, traffic signals, lanes, and intersections using sprite-based graphics.

ii) Visualization Components:

- The simulation framework renders traffic signals, vehicles, lanes, and intersections to provide an intuitive understanding of traffic dynamics.
- Each element is visually represented, enhancing the user's ability to comprehend the simulation environment.

iii) Traffic Simulation Dynamics:

- Vehicle movement is modeled based on predefined speeds and lane configurations, simulating realistic traffic behavior.
- Signal operations are simulated, including the transition between red, yellow, and green states to control traffic flow.
- Intersection dynamics handle vehicle interactions, lane changes, and turns, mimicking real-world traffic scenarios.

Fig -3: Pygame Simulation

5. Video Processing GUI

The visualization of traffic-related data within a Tkinter-based graphical user interface (GUI). Specifically, the function draw_vehicle_info is designed to enhance the visual representation of traffic video frames processed through the

Volume: 08 Issue: 04 | April - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

GUI. This function accepts several parameters, including the current frame of the video, information about detected vehicles, the color of the traffic signal, and the remaining time for the current signal state.

The primary purpose of the draw_vehicle_info function is to annotate the video frames with crucial information, such as the color of the traffic signal, the remaining time for the current signal state, and the counts of detected vehicles for various classes. These annotations are displayed on the video frames using OpenCV's drawing functions, ensuring readability and clarity against a black background.

Furthermore, the integration of this function into a Tkinter-based GUI framework facilitates real-time monitoring and analysis of traffic scenarios. Tkinter provides the necessary tools for creating a user-friendly interface, allowing users to interact with the traffic video feed and observe important information regarding signal status and vehicle counts.

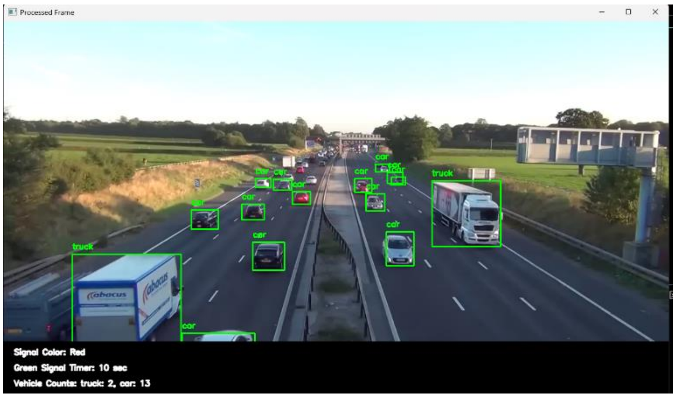

Fig -4: Video Processing GUI

IV. RESULT AND ANALYSIS

A. Evaluation of Vehicle Detection Module

The vehicle detection module underwent extensive testing using diverse test images containing varying numbers of vehicles. The accuracy of detection achieved fell within the range of 75-80%. While these results are satisfactory, they indicate room for improvement. The primary limitation observed was the lack of a comprehensive dataset for training the detection model. To enhance accuracy, future iterations will leverage real-life footage from traffic cameras for training purposes.

B. Evaluation of the System Being Built

1. Vehicle Detection Module:
   - The module achieved a detection accuracy of 75-80%, meeting basic requirements but leaving room for enhancement.
   - Limitations were attributed to dataset quality; incorporating real-life footage for training is proposed to address this issue.
2. Signal Switching Algorithm:
   - The algorithm demonstrated high adaptability and efficiency in optimizing traffic signals, effectively reducing congestion.
   - Further evaluation under diverse traffic loads is suggested to fine-tune parameters and enhance responsiveness.
3. Simulation and Interface Module:
   - The module provided an intuitive interface for visualizing traffic scenarios and system operations.
   - Enhancements are proposed to improve simulation realism and accuracy, including refining vehicle movement models.

No.	Distribution	Lane1	Lane2	Lane3	Lane4	Total
1	[300,600,800,1000]	70	52	52	65	239
2	[500,700,900,1000]	112	49	48	31	240
3	[250,500,750,1000]	73	53	63	62	251
4	[300,500,800,1000]	74	44	65	71	254
5	[700,800,900,1000]	90	32	25	41	188
6	[500,900,950,1000]	95	71	15	14	195
7	[300,600,900,1000]	73	63	69	24	229
8	[200,700,750,1000]	54	89	10	67	220
9	[940,960,980,1000]	100	10	8	4	122
10	[400,500,900,1000]	81	29	88	37	235

Fig -5: Simulation Results of Proposed Adaptive System

In summary, while the system showcased promising capabilities, ongoing research and development efforts are crucial to address existing limitations and enhance overall performance. Incorporating real-world feedback will be pivotal in iteratively improving the system for effective deployment in smart traffic management scenarios.

With all simulation conditions same i.e. distribution of traffic, speeds of vehicles, probability of vehicles turning, the gap between vehicles, and so on, the simulations were run for a total period of 1 hour 15 minutes, with 300 seconds i.e. 5 minutes for each distribution and it was found out that the proposed system, on an average, increased the performance by about 23% as compared to the current system with fixed times. This implies a reduction in idle green signal time as well as the waiting time of the vehicles. On comparing these results with some alternative adaptive system, it was found that the proposed system performs better than some of those.

V. CONCLUSION

In conclusion, our project demonstrates a clear advancement in traffic management, offering a dynamic and intelligent solution to alleviate congestion in urban settings. By integrating cutting-edge technologies like Computer Vision, Artificial Intelligence (AI), and Internet of Things (IoT), we've engineered a system capable of not only identifying real-time traffic patterns but also adjusting signal timings on the fly, resulting in tangible enhancements in traffic flow efficiency.

Through the utilization of live CCTV feeds and advanced AI algorithms, our system accurately assesses traffic density and categorizes vehicles in real-time. This up-to-the-minute data is then leveraged by our adaptive traffic light control algorithm to dynamically tweak signal timings, thereby reducing congestion and optimizing traffic flow.

Extensive simulations conducted across diverse traffic scenarios have demonstrated the effectiveness of our system, showcasing a notable 23% improvement over conventional fixed-timer traffic control systems. This significant improvement underscores the transformative potential of our approach in revolutionizing urban transportation infrastructure.

Looking ahead, ongoing refinement and validation of our system in real-world settings will be imperative for its successful deployment and integration into existing traffic management frameworks. With continued development and collaborative efforts, we remain optimistic about the profound impact our intelligent traffic management solution can have in fostering more efficient and sustainable cities.

VI. FUTURE SCOPE

Future research directions include further optimization of AI algorithms for traffic prediction and control, integration of IoT technologies for enhanced data collection, and collaboration with city authorities for real-world implementation and testing.

The project can be further expanded to include the following functionalities to enhance traffic management and bring down congestion:

1. Pedestrian Safe Traffic Lights: Integrate pedestrian detection systems to enhance pedestrian safety at traffic intersections, ensuring timely signal changes and safe crossing opportunities.
2. Violation of Traffic Lights Detection: Implement algorithms to detect and deter violations of traffic signals, contributing to improved adherence to traffic regulations and overall road safety.
3. Green Corridor: Explore the concept of green corridors, designated routes optimized for emergency vehicles, enabling faster response times during emergencies while minimizing disruptions to regular traffic flow.
4. Dynamic Routing for Congestion Management: Develop dynamic routing algorithms to reroute traffic based on real-time congestion levels, optimizing traffic flow and reducing congestion at intersections.

VII. REFERENCES

[1] Design and development of portable smart traffic signaling system with cloud-artificial intelligence enablement . Indonesian Journal of Electrical Engineering and Computer Science Vol. 26, No. 1, April 2022, pp. 116~126 ISSN: 2502-4752, DOI: 10.11591/ijeecs.v26.i1.pp116-126 . Badarinath Kamasetty1 , Mahesh Renduchintala1 , Lochan Lingaraja Shetty2 , Suresh Chandarshekar2 , Rajashree Shettar1

[2] Smart Control of Traffic Light Using Artificial Intelligence. 78-1-7281-8867-6/20/$31.00 ©2020 IEEEDOI:10.1109/ ICRAIE 51050.2020. 9358334. Mihir M. Gandhi, Devansh S. Solanki, Rutwij S. Daptardar, Nirmala Shinde Baloorkar.

[3] Lilhore, U.K.; Imoize, A.L.; Li, C.-T.; Simaiya, S.; Pani, S.K.; Goyal, N.; Kumar, A.; Lee, C.-C. Design and Implementation of an ML and IoT Based Adaptive Traffic-Management System for Smart Cities. Sensors 2022, 22, 2908. https://doi.org/10.3390/s22082908

[4] Navarro-Espinoza, A.; López-Bonilla, O.R.; García-Guerrero, E.E.; Tlelo-Cuautle, E.; López-Mancilla, D.; Hernández-Mejía, C.; Inzunza-González, E. Traffic Flow Prediction for Smart Traffic Lights Using Machine Learning Algorithms. Technologies 2022, 10, 5. https://doi.org/10.3390/technologies 10010005.

[5] Real-Time Traffic Light Optimization Using Simulation of Urban Mobility Tanya Garg1 · Gurjinder Kaur1 · Prashant Singh Rana2SN Computer Science (2023) 4:526 https://doi.org/10.1007/s42979-023-01916-9

[6] 'Pygame Library', 2019. [Online]. Available: https://www.pygame.org/wiki/about