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Smart Control of Traffic Light System using Artificial Intelligence

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***Abstract*:** Traffic congestion is a growing urban challenge, leading to delays, wasted fuel, and safety issues. This project introduces an flexible traffic light control system using artificial intelligence to ease congestion, cut wait times, and improve road safety. Reducing Traffic Congestion: By adjusting traffic light timings based on real-time data, the system enables smoother traffic flow at busy intersections, reducing delays and improving overall travel times. Optimizing Traffic Signal Timings: Using AI algorithms, the system efficiently manages green and red phases to meet the varying demands of traffic throughout the day, adapting dynamically to peak hours and minimizing stop-and-go situations. Enhancing Road Safety: The system prioritizes high-risk scenarios, such as emergency crossings, by adjusting signals to reduce accident risks, creating a more secure environment for both motorists and walkers.

Keywords- Smart traffic light control, Artificial intelligence in traffic control, flexible signaling systems, and smart transportation technologies (ITS), Traffic congestion reduction, Real-time traffic data, Signal timing optimization.

I. INTRODUCTION

As urban populations grow and more vehicles fill our on roadways, traffic jams have turned into a pressing challenge for cities worldwide. The consequence of traffic jams extends far beyond delays and frustration for drivers; they also lead to increased fuel consumption, higher transportation costs, and greater carbon emissions, taking a toll on both the economy and the environment.

Factors like limited road capacity, high demand during rush hours, and lengthy red-light delays all contribute to congestion. Traditional traffic lights, which operate on fixed schedules, often struggle to adapt to changing traffic patterns in real-time, creating inefficiencies that exacerbate the problem. This highlights the urgent need for smart traffic signal control systems. By using AI to adjust signals dynamically based on live traffic conditions, these systems can enhance traffic movement, minimize emissions and fuel consumption, and ultimately provide a smoother and safer experience for everyone on the road.

II. LITERATURE SURVEY

In 2018, Thorpe introduced a neural network- based value function for predicting waiting times at intersections. By 2023, researchers demonstrated that deep Q-learning methods could significantly reduce vehicle waiting times. Additionally, intelligent agents have been developed to optimize traffic signaling through local decision-making. Innovative systems using visual processing for vehicle identification further enhance traffic management adaptability (G. Sathya et al., 2023).

Urban life is increasingly hectic due to population growth, leading to a significant rise in motor vehicles and traffic congestion (Carley and Christie, 2017). Traffic signals, designed to manage flow at busy intersections, often fail when certain lanes experience heavier traffic. This results in overcrowding in some lanes while others remain underutilized. Innovative automated traffic control systems can optimize signal timings to improve vehicle movement and reduce congestion.

Divyansh Bagdi's 2021 literature survey provides an in-depth analysis of traditional traffic management systems, highlighting key issues and drawbacks associated with traditional traffic light management. The chapter discusses the signalized traffic system commonly implemented in urban areas, examining its effectiveness and the various types of traffic lights currently in use. It emphasizes that traditional systems often fail to manage traffic efficiently, particularly when certain lanes experience heavier congestion than others. This inefficiency leads to overcrowding in some lanes while others remain underutilized, necessitating a reevaluation of existing traffic management strategies.

Seyedeh M. Mortazavi Azad and A. Ramazani's paper, received on August 2, 2023, and accepted on November 6, 2023, explores the use of traffic lights in urban areas to prioritize vehicles at intersections as a solution for traffic control. The authors focus utilizing machine learning methods, particularly Q-learning coupled with deep neural networks, implemented in two intersection models: one for an individual intersection and another for two connected intersections sharing actions. Their approach allows traffic lights to make intelligent decisions that reduce vehicle waiting times by effectively managing phase allocations. Simulations conducted using SUMO revealed a 34% reduction in average queue time at individual intersections and a 24% reduction in queue time across two intersections during heavy traffic scenarios.

P. Joyson Silva, R. Vignesh, Binu Sukumar, and Nithish Kumar's 2023 research addresses the inefficiencies of India's traffic control systems, which struggle with unpredictable traffic density patterns. They propose an adaptive traffic light timer that uses image processing algorithms with a Raspberry Pi and OpenCV to analyze real-time traffic conditions. This system minimizes vehicle waiting times and increases the amount of vehicles passing by each lane, significantly improving traffic circulation. The strategy is noted for its efficiency and cost-effectiveness compared to existing methodologies.

III. EXISTING SYSTEM

The overcrowding of city traffic is emerging as a major problem due to the rising population and amount of vehicles in metropolitan areas. Traffic bottlenecks not only lead to additional delays and stress for drivers but also raise fuel consumption, increase transportation expenses, and contribute to higher carbon dioxide emissions.

Various factors can contribute to traffic congestion, such as inadequate capacity, unchecked demand, long red light delays, and so on. Traffic signals play a crucial role in influencing traffic movement.

Advantages:

1. **Real-Time Traffic Adaptability**: AI-driven systems can monitor live traffic data and adjust traffic signals moment- to-moment, accommodating peak hours, special events, or unexpected incidents like accidents, which helps prevent traffic bottlenecks.

2. **Decreased Travel Time**: With AI optimizing the timing of lights, vehicles can maintain smoother flows through intersections, significantly reducing average travel times across a city. This also improves driver satisfaction by reducing frustrating delays.

3. **Reduced Fuel Use and Environmental Impact**: By minimizing the frequency of stops and idling time at lights, AI-controlled systems cut down on fuel usage, which can lead to noticeable reductions in emissions and pollution levels in busy urban areas.

4. **Intelligent Priority for Special Vehicles**: Emergency vehicles, public transport, and school buses can be prioritized, giving them green lights for faster, safer travel. This not only improves emergency response times but can also encourage the use of public transportation by making it more efficient.

5. **Advanced Analytics and Forecasting**: AI systems can manage substantial quantities of historical and live traffic data, predicting patterns and enabling long-term planning and improvements in urban traffic management.

6. **Less Need for Human Intervention**: Automated traffic light management reduces the requirement for on-site manual adjustments, freeing liberate human resources for other crucial traffic or city management tasks.

Disadvantages:

1. **High Infrastructure and Setup Costs**: Implementing AI-driven traffic systems requires investments in high- tech equipment like cameras, sensors, and control systems. In many cities, retrofitting existing traffic infrastructure with AI capabilities can be costly.

2. **Data Privacy and Security Risks**: The data needed for real-time traffic management, often collected from cameras or connected devices, may raise privacy concerns. Without proper safeguards, sensitive information could be misused or exposed to cyber threats.

3. **Dependence on Network Connectivity**: Many AI-based traffic systems rely on stable internet or network connections. Connectivity issues can lead to inefficiencies or errors in signal timing, especially in rural or Isolated regions where network infrastructure could be lacking.

4. **Complex System Maintenance**: AI systems require ongoing maintenance to remain effective, including regular updates and troubleshooting of both hardware and software. Cities without resources for regular maintenance might struggle to keep these systems functional.

5. **Cybersecurity Vulnerabilities**: As AI- based systems become more interconnected with city infrastructure, they become desirable targets for cyberattacks. A security breach could disrupt traffic on a large scale, with potential consequences for public safety.

6. **Possible Inefficiency in Low Traffic**: In areas with low or highly variable traffic volumes, the added complexity of an AI traffic system may not justify the investment, as simpler, timed light systems might perform nearly as well without the costs associated with AI.

7. **Resistance from Public and Stakeholders**: Changes in traffic patterns, such as adaptive timing, might initially frustrate drivers accustomed to fixed light timings. This can lead to resistance or reluctance among the public and local authorities, slowing down the adoption of AI-based solutions.

IV. PROBLEM SYSTEM

Manual Traffic Control: In manual traffic control, traffic police are stationed to direct traffic flow using handheld signboards, lights, and whistles. While effective in areas needing close supervision, this technique is labor- intensive and dependent on human existence, which could lead to inconsistencies and limited coverage, especially in larger or busier areas.

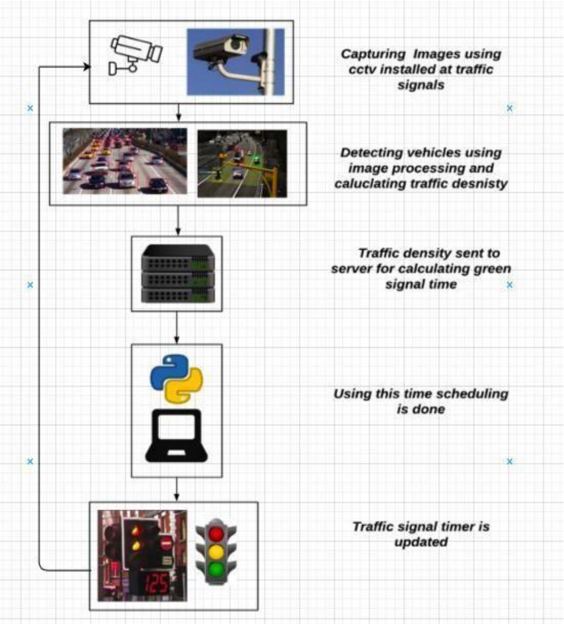
Automatic Traffic Lights: Automatic traffic lights rely on fixed timers with pre-set numerical values to control light changes. Although automated, this system lacks flexibility and cannot adapt to real-time traffic conditions, leading to inefficiencies such as long waits during off-peak times or congestion during peak hours.

Electronic Sensors: Advanced traffic systems use sensors like inductive sensors or proximity switches embedded in roads to monitor traffic circulation and control lights accordingly. However, these systems can be costly to implement and maintain, and they are susceptible to environmental interference and wear over time. Additionally, sensor-based systems may still lack the sophistication needed to handle complex, unpredictable traffic patterns in urban areas, leading to potential inefficiencies.

V. PROPOSED SYSTEM

Traffic flow is highly unpredictable, and static signal timers exacerbate congestion by failing to adapt to real-time traffic conditions. To address this, a system that dynamically calculates optimal green light durations based on current traffic levels at each signal would be far more effective. By allowing the direction with heavier traffic to receive a longer green light, and reducing the wait for less congested directions, this adaptive approach can greatly improve traffic flow. Unlike traditional systems with fixed, hard-coded light patterns that lead to unnecessary delays, this responsive system can reduce congestion, shorten waiting times, and decrease the likelihood of accidents. Additionally, by cutting down on idling, it can reduce fuel consumption, thus contributing to lower air pollution levels in urban areas.

The primary goal of this initiative is to develop a traffic light regulation system employing Computer Vision that adapts in real-time to current traffic conditions. Our proposed system leverages live video streams from surveillance cameras at intersections to calculate traffic density by detecting and analyzing vehicles at each signal. Based on this data, the system dynamically adjusts the green light duration to optimize traffic flow. To ensure precise timing, vehicles are grouped into types such as cars, bikes, buses/trucks, and rickshaws, allowing for a more accurate calculation of the required green signal time.



Our envisioned system will assess snapshots from CCTV cameras at intersections to assess traffic patterns in real time through Image manipulation and Computer Vision. To detect vehicles, we employ a customized YOLO (You Only Look Once) object detection specifically tailored for object detection. Using this traffic density data, a scheduling algorithm will determine the optimal green light phase for each signal and adjust the stop signal times for the other directions accordingly. This dynamic approach aims to enhance traffic circulation and minimize congestion by responding to real-time traffic conditions at each junction.

VI. ALGORITHMS

The Signal Switching Algorithm adjusts the go signal duration depending on the traffic density data provided via the vehicle detection module, while updating red light timings for other directions. The algorithm operates in a cyclical manner, switching signals according to each timer. It receives input from the sensing module, which provides vehicle data in JSON structure, with each detected vehicle labeled as a key, accompanied by confidence levels and coordinates as values.

The algorithm parses this data to determine the total count of each vehicle type, which is then used to calculate the optimal green light duration. Red signal times are adjusted for other directions accordingly. This algorithm is intended to be scalable, allowing for application across any quantity of signals at an junction.

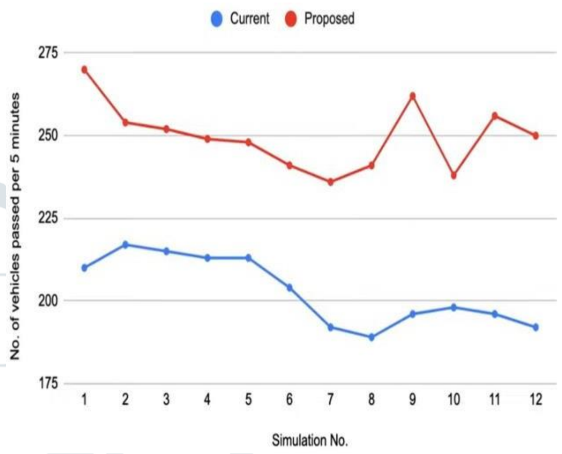
The Algorithm was developed with the following key factors in mind:

1. Processing Time: The duration needed for the algorithm to compute traffic density and determine the interval of the go signal, which informs the optimal moment for image capture.
2. Lane Count: The lane count at the junction.
3. Vehicle Counts by Class: The overall vehicle count in each category (cars, trucks, motorcycles, etc.).
4. Traffic Density: Calculated according to the above factors.
5. Start-Up Delay: The lag encountered by each vehicle during start-up, together with the increasing, non-linear delay affecting vehicles further back in the queue.
6. Average Speed per Vehicle Class: The average time taken for each vehicle class to clear the intersection once the go signal is activated.
7. Green Light Duration Limits: Minimum and maximum time thresholds for the green phase to prevent prolonged waits and traffic congestion.

1. RESULTS

We conducted a comparison of the overall vehicle count passing across the junction over five-minute intervals, evaluating both the current system and the proposed adaptive system. Using identical traffic distributions, we ran 12 five-minute simulations over a one-hour period, varying traffic distributions across each simulation. The results are presented in a table, showing the lane-wise vehicle counts as well as the overall vehicle count that passed through the intersection.

With identical conditions, the adaptive system allowed 2,997 vehicles to pass in one hour, compared to 2,435 in the present static system—an increase of 562 vehicles. This demonstrates a performance boost of over 23%.



On average, the adaptive system enables 48 additional vehicles to pass every five minutes relative to the static system. This indicates a decline in both unused go signal time (when the signal is green, but no vehicles are present vehicles pass) and vehicle waiting times.

VIII. CONCLUSION

The suggested adaptive traffic control system dynamically adjusts green signal durations based on real-time traffic volume at each signal. By allocating longer green times to directions with higher traffic volumes, the system reduces unnecessary delays, minimizes congestion, and shortens waiting times. This efficiency not only improves the flow of vehicles through intersections but also helps reduce fuel consumption and emissions, supporting a cleaner urban environment.

Simulation results indicate that the adaptive system achieves approximately 23% greater vehicle throughput compared to the traditional static system—a significant improvement. On average, this system allows more vehicles to cross the intersection per cycle, decreasing overall idle time and smoothing the flow of traffic. Integrating this adaptive system with existing CCTV infrastructure in major cities would enable a more responsive and efficient traffic management solution, allowing real-time adjustments to signal timing based on current traffic conditions. This capability can greatly enhance urban mobility, reduce pollution, and enhance the living conditions for city residents by making commutes shorter and less stressful. The system represents a forward-thinking approach to managing the growing demands on urban traffic networks.

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