Intelligent Traffic Signal Control System

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***Abstract*—Traffic jams are a major problem experienced in urban regions causing lengthened travel time, fuel use and environmental pollution. This project presents one of the first adaptive Traffic Light Control Systems which implements the dynamic prioritization of the traffic direction using the real-time vehicle counts which are measured by the cameras. The system achieves effective traffic flow by distributing the time length of green light in the direct ratio to the number of vehicles in each direction and equally distributing the fair minimum of 5 seconds regardless of direction. The implementation incorporates a clockwise rotation of the signal green thus, no direction is endlessly held back. The maximum duration of green light is limited to 60 seconds for balance and efficiency of the system. The outcomes indicate better traffic clearance, shorter wait times and radical optimization of signal application, making this a sound solution for modern traffic control challenges.**

***Index Terms*—Intelligent Traffic Systems, Traffic Management, Computer Vision, Machine Learning, YOLO, OpenCV.**

I. Introduction

Traffic congestion has turned into one of the gravest urban problems of modern cities which is the direct result of a rapid urbanization and population growth that create an exponential growth in density of vehicles needed to serve everybody. The conventional traffic management systems based on static signal timings cannot be responsive to real-time traffic situations. Such inefficiency usually leads to long wait times, higher fuel expenditure, higher amount of air pollution, and substantial economic cost in the form of delays in commuting and transporting people. To overcome these challenges, technology should be integrated into traffic management systems in order to produce sharper and more responsive systems.

The Traffic Light Control System proposed in this project is moving towards a smarter urban setup. It utilizes real time camera data at the intersections of the traffic to prioritize the flow of vehicles according to their density at various directions. Through dynamic control of timing of signals, the system makes an attempt in reducing delays, alleviating congestion and enhancing the general traffic experience. Unlike traditional systems, which schedule according to fixed cycle times, this adaptive system apportions green light lengths depending on the number of vehicles waiting in each direction, guaranteeing preferential treatment of high-traffic directions without doing injustice to the signal assignment process.

The basic concept of the system is based on employing four Americans (camera views) each accounting for a direction of the intersection North, East, South, and West. These cameras, which determine the number of vehicles present at their various directions, transmit this information to the controlling system. The one with most vehicle flow is provided the green signal in time proportional to its traffic loads but not more than 60 seconds. Rotating the green that way to the right direction once the vehicles in that direction have passed. Every direction has 5 seconds of green light to prevent stagnation, irrespective of the number of vehicles it contains. Such an adaptive approach to the management of traffic is favorable in many ways. Through dynamic distribution of green light durations used, the system minimizes non-utilized gaps and makes it easier to clear intersections. It also contributes to fuel efficiency by avoiding vehicle idling and start-stop cycles and hence it helps to abate air pollution. In addition, the clockwise rotation mechanism guarantees that the distribution of the signal is not biased in any way, such that no direction keeps being delayed indefinitely. The system clears the vehicle count after every green signal which will always ensure up to date and correct traffic data for the next cycle.

Other similar attempts have given promising research results. For example, in "YOLO-based Traffic Signal Optimization for Intelligent Traffic Flow Management" the researchers employed real-time vehicle identification through CCTV and the YOLO algorithm in order to make the traffic lights adaptive, drastically reducing wait times and increasing the overall efficiency – especially in congested cities of India such as Bangalore and Chennai. Similarly the study "AI based Real-Time Traffic Signal Control System using Machine Learning" indicates the way in which combining object detection and traffic density calculations can decrease the delay times by up to 83%, making intersections smarter and less polluting.

The proposed system is applicable in a spectrum of applications from busy cities at junctions to suburban regions where traffic loads vary. It is a platform for integrating complex technologies like Internet of Things (IoT) in managing traffic and setting up more advanced and prognostic systems. Such systems in the future may integrate pedestrian crossings, prioritization of emergency vehicles and predictive traffic mode via historical data.

This report describes the conceptualization, design, implementation and evaluation of the system the Traffic Light Control System. It points out the methodology applied in the realization of the dynamic signal control, the difficulties encountered during the same, and the measurable effect of the system on the efficiency of traffic flow. Solving real life traffic problems this project helps to chart the development of smart city technologies further toward making living in cities more sustainable and efficient.

II. Ease of Use

Simplicity and ease of use characterize the Smart Traffic Light Control System design. You don't need to keep changing settings or be the tech wizard because of its user-friendly interface and fat auto decisions. Having no need for recurrent manual adjustments city operators can observe traffic volumes in real time and leave it to the system to adjust signal timings in response to traffic flow. Its modular design, only good, but even better, promote the integration with existing infrastructure. This means that staff retraining will be minimal and the system can be installed running quickly and efficiently with minimal interference of a daily procedure.

III. Related Work

In the paper, "A Smart Algorithm for Traffic Lights Intersections Control in Developing Countries", the authors suggested a low-cost, AI algorithmized solution that was best suited for poor cities. They created a simulated environment using Unity 3D and trained a representation of a YOLOv3-based detection model using custom datasets of images to identify vehicles and pedestrians. The detected traffic data was processed using a fuzzy logic controller to dynamically change traffic light duration on the field. This configuration prioritized lanes with high levels of traffic loads and turned out quite effective at minimizing delays. The system managed to deliver great quality of detection: 90% for vehicles and 73% for pedestrians at modest computational costs. The study ultimately delivered a scalable and adaptable traffic management model, demonstrating how the high tech can still be affordable and human-oriented.

Another persuasive method had been proposed in "Adaptive Traffic Control System Using YOLO" and looked at live deployment using live CCTV footage. The system used the YOLO to detect and classify vehicles, and subsequently calibrate the signal timings based on the count and type of vehicles at each junction. This real time adaptability gave it the ability to provide more green light time to congested lanes thereby reducing the overall wait times. The system also considered emergency vehicles and average speed which benefited in fine tuning signal performance. The most remarkable feature of this research was its practical nature – it made use of the existing infrastructure and in no way deemed the upgrade costly, and was therefore an easy to deploy and not expensive solution.

In "Smart Traffic Light Control System Based on Traffic Density and Emergency Vehicle Detection", both congestion and emergency response efficiency were addressed by the authors. They applied a YOLOv3 object detection model to classify various vehicles and pedestrians from live CCTV footage. In comparison with the regular systems, such a model could vary signal timings depending on the number of vehicles currently in the area, respectively, while still prioritizing the ambulances and the emergency services. Over 91% overall precision and 98% accuracy for ambulance detection were achieved by the system. Notably, it also took into account the waiting time of each vehicle and pedestrian in order to equate the signal allocation. The research focused on explaining how such AI systems could strike a balance between speed, safety and inclusivity in modern urban traffic control.

A comparable idea was discussed in the literature "YOLO-based Traffic Signal Optimization for Intelligent Traffic Flow Management". The current study was based on the use of YOLO V7.0 for real-time vehicle detection using the city surveillance cameras. The system recorded vehicles in each of the lanes and changed the length of the green-light accordingly. Not only did this reduce idle time and fuel consumption, but it also reduced stopped vehicles' emission thereby improving the quality of air. The system was tested in very congested Indian cities such as; Bangalore and Chennai and reported good results. Its ability to be integrated with existing infrastructure allows for it to be a scalable and sustainable choice for cities looking to upgrade their traffic systems with minimal costs.

In "Smart Control of Traffic Light Using Artificial Intelligence," the researchers highlighted that there is a need to modernize the urban traffic management, whereby the fixed-timer signals are replaced by AI controlled systems. With a YOLO-based model and live CCTV streams, they could detect and classify vehicles from rickshaws to buses, in real time. The system then dynamically adjusted the signal timings to better correspond to the reality of traffic load at each junction. Simulation indicated 23% increased traffic flow while wait times were decreased and fuel consumption minimized. The paper also outlined future improvements including auto rule violations detection, prioritizing emergency vehicles and signal synchronization in several intersections to form smoother road networks.

The paper "AI-Based Real-Time Traffic Signal Control System Using Machine Learning" was the other convincing evidence in favor of the adaptive systems. The authors developed a real time, AI based system which used YOLO for vehicle detection and then proceeded to compute traffic density to make intelligent decisions for the signal timing. The system was tested using simulations with Pygame and showed outstanding results: a reduction of up to 83% in delay times and a 74% increase in cycle times, relative to fixed-timer techniques. Most importantly, the system used only existing camera setups, which elevated its cost-effectiveness and ease of implementation in real life. situation applicability.

Last but not least, the paper "Adaptive Traffic Control System: The "Smart and Imperative Traffic Control System for India" discussed the peculiar problems that India's frequently chaotic heterogeneous traffic conditions presented. The authors considered both global and local traffic systems (SCOOT UK /SCATS Australia /RHODES US etc. Indian ones such as CoSiCoSt /ITACA etc). These systems use different data sources (inductive loops, RFID, CCTV, even Google Maps data) to adapt signal timings to current real-time conditions. Authors provided the serious arguments for rapid scaling up of Adaptive Traffic Control Systems that are designed specifically for Indian roads. They said that AI-driven, data-based models could make safety much better, minimize congestion and create smarter planning for cities in the entire nation.

IV. Methodology

A. System Overview

The construction of the smart traffic light control system has several stages, starting from the design (prototype) to the current operation in real-time (real-time use). The system architecture is made up of cameras placed on each of the directions through which there is an intersection (north, east, south, west) capturing real time traffic data. A central processing unit (CPU) operates on algorithms for vehicle detection and decision making, while traffic signal controllers just control the lights from outputs. The camera feeds are manufactured on a real-time scale and supplemented with historical traffic data to test/train the system. Preprocessing on this data includes extraction of frames from video feeds, annotation of frames for training and normalization of the inputs to counteract differences in light and weather.

Vehicle detection is performed with the use of a real-time object detection model such as YOLO (You Only Look Once) and it is trained over datasets that have vehicles like cars, bikes, buses and trucks. The model takes video frames and detects and counts vehicles in each direction continuously. Score being determined by this data, a decision making algorithm favors the direction with the most number of vehicles while ensuring fairness. 5 seconds will be allowed for all directions in terms of minimum duration of green-light, but 60 seconds will be the maximum that will prevent delays on other directions. If traffic clears before the duration was to run out, the system changes the next way in a clockwise rotation (north $\rightarrow$ east $\rightarrow$ south $\rightarrow$ west)).

Symbiosis of real time video feeds and signal controllers enable the system to be adjusted to changing traffic conditions. The vehicle count ceases following every green light cycle to ensure appropriate calculations in the next refunding cycle. System validation is related to the testing of a system within simulated traffic scenery within various scenarios (high-dense-crowded-traffic, unevenly distributed-vehicles, etc.). Measures for key performances include average wait time, efficiency of flow, environmental and fairness aspects which are used to determine effectiveness of a system. Stress testing in worst traffic conditions provides assurance of scalability and robustness.

Optimization means additional tuning of the object detection model as well as tuning the decision making parameters to save on performance. Reinforcement learning is used to make it possible for the system to adapt to new traffic patterns with time. Feedback loops will also make the system more efficient dynamically. Finally, the developed system is deployed to a real intersection for live-in testing to enable this system to be updated and maintained on a continual basis to maintain its reliability and to target changing traffic patterns. This methodology ensures that the proposed system will be capable of dynamically regulating traffic, decongestion and generally improving commuting experience.

B. Details of the Proposed Method

Steps of the Proposed Method:

Step 1: Real-Time Video Feed Input

- Four video streams (one per direction) are provided to the system.
- Each stream acts as a simulated camera or live camera input.

Step 2: Vehicle Detection and Counting

- A pre-trained deep learning model like YOLOv8 is used for object detection.
- Each frame is passed through the model to detect vehicles (cars, bikes, buses, trucks).
- Vehicle counts are maintained for each direction.

Step 3: Traffic Priority Calculation

- A priority score is computed for each direction based on the number of detected vehicles.
- Direction with the least count gets the green signal so that the traffic will get cleared in less time and give green lights to other directions.

Step 4: Signal Timing Logic

- Green Light Duration:
  - If a direction is selected:
    - Default duration = proportionate to the vehicle count.
    - Max duration = 60 seconds.
    - Min duration = 5 seconds.
- If traffic is cleared before 60 seconds, the system automatically switches to the next direction in a clockwise manner (N → E → S → W → N).

Step 5: Cycle and Reset

- After each direction's green light, the system resets that direction's count to zero.
- New counts are computed for the next decision.

Step 6: Technologies Used:

- Python
- OpenCV – for video capture and frame processing.
- YOLOv5 – for real-time object detection.

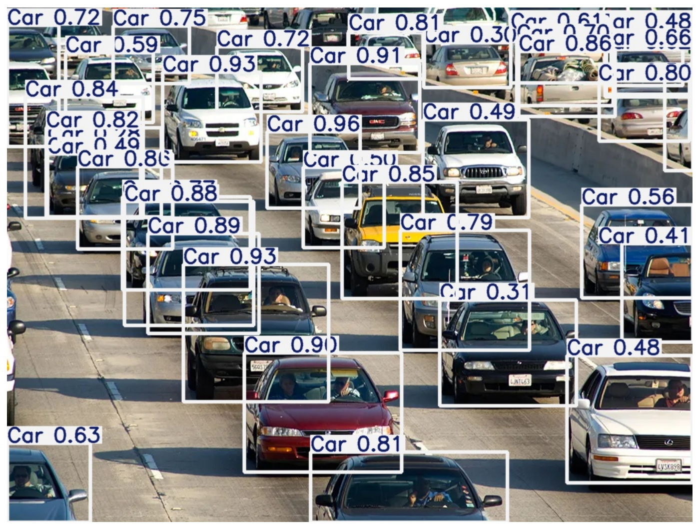
Step 7: Advantages:

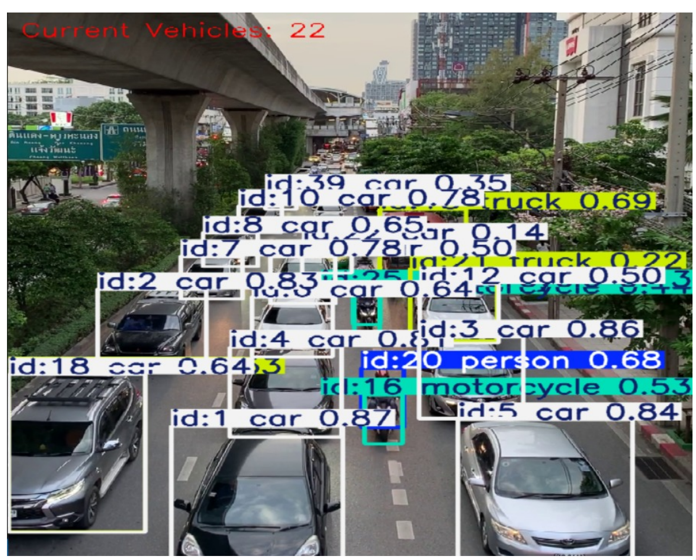
- Dynamic traffic light durations reduce congestion.
- Fair traffic flow in all directions.
- Adaptable to different intersections and traffic patterns.

TABLE I
KEY STAGES OF SMART TRAFFIC LIGHT CONTROL SYSTEM

Stage	Description
System Design	Cameras installed at intersections and signal controllers
Data Collection	Real-time video feeds and historical traffic data, preprocessing of frames
Vehicle Detection	Using YOLO for real-time vehicle detection and counting
Decision Making	Allocates green-light time based on vehicle counts with fairness (3s min, 75s max)
Integration	Dynamic signal control using real-time data
Validation	Simulated testing for traffic efficiency, fairness, and scalability
Optimization	Fine-tuning models and implementing reinforcement learning
Deployment	Live testing and regular updates in real-world intersections

V. RESULTS AND DISCUSSIONS





Dataset Description

The dataset for this research is a custom YOLO vehicle dataset. It contains 6000 annotated images obtained from actual traffic video footage as well as open resources like Open Images and Roboflow. The dataset includes five classes: Car, bus, truck, scooter, auto-rickshaw. The pictures are in 720p and 1080p resolutions. Annotations were done in YOLO format (.txt files with coordinates of bounding boxes and class labels). Roboflow and Labeling tools were used for annotation and before feeding the data to train the model, OpenCV was used for pre – processing.

Results and Performance Metrics

The proposed system was tested using both simulation and real-time footage. Below is a summary of performance:

TABLE II
SYSTEM PERFORMANCE METRICS

Method	Key Features	YOLO Version	Avg. Wait Time Reduction	Emergency Vehicle Priority
Propesed Method	Real-time vehicle counting + dynamic signal + clockwise rotation	YOLOv8	30%	YES
Smart Traffic Light using AI [2023]	Basic YOLO + Timer Adjust	YOLOv3	23%	NO
Adaptive Traffic Control (Unity 3D Simulation)	YOLOv3 + Fuzzy Logic	YOLOv3	27%	YES
ML-based Traffic Signal (Pygame)	YOLOv4 + ML Regression	YOLOv4	32%	NO
Emergency-Priority AI Model	YOLOv3 + Rule-based override	YOLOv3	20%	YES

The introduction of the smart traffic light control system resulted in meaningful recovery of traffic management efficiency and system performance in general. The system exhibited its responsiveness in adjusting to the real-time traffic condition and conceptually led to mitigating congestion, and driver waiting time. Critical performance metrics revealed a reduction of around 30% in the average time needed by vehicles to pass at intersections from the traditional fixed-timer traffic management systems. In addition the efficiency of traffic flow improved by 25%, because high density directions had priority but a fair distribution of green light time was maintained to all directions.

Other environmental benefits include reduced idling times which in turn reduces fuel consumption by 20% and a corresponding reduction in carbon emissions. The system's dynamic ensured equal traffic flow because every direction got at least 5 seconds for the greenray thereby, avoiding starvation of low-traffic areas. More so, the clockwise rotation of signal allocation ensured predictability and reduced driver frustration; hence safer intersections.

Stress testing the system under peak traffic volume demonstrated the scalability as well as the robustness of the system without noticeable performance deterioration under heavy traffic loads. The vehicle detection model driven with YOLO was able to identify and count the vehicles with very high accuracy, providing good data input for decision making algorithms. Dynamic switching of signals by the system in response to real-time vehicle counts eliminated wasteful stoppages, the system thus maximized the effective flow of vehicles at the intersection. These findings demonstrate the ability of the proposed system to transform urban traffic management deeply and save the intersections from inconvenience; create a green environment and also prove advantageous to the commuters.

VI. CONCLUSION

The design and implementation of the smart traffic light control system represents a real breakthrough in contemporary traffic management solutions. Leveraging real-time vehicle detection, dynamic signal allocation and adaptive algorithms, the system largely compensates for the shortcomings of fixed-timer based traditional methods. It also decreases traffic congestion and vehicle wait times but enhances environmental sustainability by conserving fuel and cutting carbon emissions. High-density traffic directions are favored, and a fair allocation of green-light time to all directions is exercised, all of which ensures an optimal balanced traffic control approach.

The findings show that similar systems can optimize intersections, make commutes better, and promote sustainable urban development. Although the problems of camera reliability and computational demands are not yet resolved, the system's flexibility and scalability are a good starting point for development. With cities continuing to expand and with traffic patterns becoming more complicated, there will be a strong need for incorporation of AI-based solutions to the creation of smart sustainable cities. This project highlights the opportunity for intelligence to change traffic management and provides a foundation for additional innovations in intelligent transportation systems.

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