Computer Vision Enabled Dynamic Traffic Light Control for Urban Mobility

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***Abstract*— Urban traffic has become a burning issue throughout the world with high travel durations, high fuel usage, and pollution of the environment. Conventional traffic lights work at a set time frame whereby they do not rely on the actual traffic density, which makes them ineffective in regulating traffic. The proposal is known as Computer Vision Enabled Dynamic Traffic Light Control in Urban Mobility and proposes an intelligent system that aims to use computer vision and artificial intelligence to optimize traffic on-the-fly. The offered model relies on live video feeds on a camera placed at intersections to identify and count the number of vehicles in each lane based on image processing and object detection algorithms, including YOLO and motion tracking on OpenCV. This system then uses real time to regulate the amount of time the green and red lights spend on the road based on the traffic density to maintain a smooth flow of traffic and minimizing on the amount of time spent in the red light. The system can also detect the emergency vehicles and pass them preferentially. The suggested solution contributes to the efficiency of the road system, decreases air pollution, and contributes to the creation of intelligent cities. The system provides a solution to the contemporary challenges of transportation in the city through constant learning and flexibility, which is innovative and long-lasting.**

***Index Terms*— Computer Vision, Dynamic Traffic Light Control, Artificial Intelligence, Smart City, Urban Mobility, Machine Learning, Real-Time Traffic Management, Image Processing, YOLO Algorithm, Intelligent Transportation System (ITS).**

I. INTRODUCTION

Traffic jams experienced in the cities around the world have been worsened by the high rate of urbanization and the high rate of addition of vehicles to the roads. Traffic control has become a major concern of local state authorities and urban planners with urban population growing at unprecedented rates. The traditional traffic lights are an extension of the conventional traffic lights where the time is hard-coded and thus the green light appears and ends after particular cycles irrespective of the present-time weather. Though this has been effective in execution, it lacks efficiency especially during the peak hours or during emergencies, when the traffic at the various lanes and crossing each intersection may have a wide range of numbers.

The drawbacks of the conventional systems have a number of negative implications. Fragmentation of time because of long queues at red lights leads to frustration among drivers and also waste of fuel which leads to air and noise pollution. In addition to this, the uncertainty created by traffic jam may slow down emergency services like ambulances, fire fueled cars and police cars which endangers lives. The solution to these issues is a dynamic and smart method that is able to act and respond to varying conditions of traffic.

Over time, the last few years witnessed the development of computer vision and artificial intelligence (AI), which has created new opportunities in addressing the problem of complex mobility in urban environments. The application of computer vision (that will allow machines to read and analyze visual data in reality) will allow regulating and controlling traffic systems automatically. Intersection cameras have the ability to record live video feeds of traveling cars, which can be further analyzed with the help of algorithms identifying, categorizing, and counting vehicles in real time. The system will be able to calculate the defined times to use by the traffic lights to minimize congestion and enhance the efficiency of the traffic flow by using density in the individual lanes. Computer vision and the dynamic traffic light control have multiple important benefits of their integration.

First, it is allowing real-time decision-making to be made, i.e., the signal durations can be created real-time in dependence on the changing vehicle densities. Second, it aids in emergency vehicle priority, in which the system identifies appearance of sirens or vehicle models of ambulances and gives them direct edge over way. Third, the system helps in greening the environment based on the fact that it will lessen vehicle idling periods thus, cutting down the fuel use as well as carbon emissions.

There are limitations on traditional solutions such as sensor-based systems or timer-based systems. Although inductive loop sensors and infrared detectors are handy, they are costly in their installation and maintenance. They also possess a low coverage and worsen in cases of harsh weather conditions. A vision-based system on the contrary is cost-effective and scaleable. Cameras are able to show more space, and the algorithms in AI could constantly enhance their performance due to machine learning.

In this project, images have been processed with the help of advanced tools of computer vision, including OpenCV (Open-Source Computer Vision Library), and trained on object detection and classification systems using deep learning models, including TensorFlow and PyTorch. Models like YOLO (You Only Look Once) and Faster R-CNN (Region-based Convolutional Neural Network) are put in effect to detect vehicles in real time with great precision. The system counts the number of vehicles in each lane by fading through video frames of live video feeds and changes the duration of the traffic signal dynamically depending on the proportion of vehicles waiting in each direction.

There are three key modules of the system architecture:

Data Acquisition Module - CCTV cameras will be placed at intersections to record real-time images.

Processing Module - Video frames are analyzed through AI artificially intelligence that makes vehicles identification and classification.

Control Module - The traffic timing at the light is determined depending on the data that is analyzed.

The system uses adaptive control algorithm in order to control efficiency by calculating the best green light time per lane. The time is relative to the density of the traffic; when the green is high, the lanes are allocated more time contrary to when the versions are on traffic that are watered with less traffic having less green time. The algorithm is dynamic and it changes with every cycle as the conditions change.

Moreover, it is capable of being connected to the IoT (Internet of Things) infrastructure to communicate with the traffic lights in the city. This interconnectivity makes it possible to have coordinated signal controlled which may enhance the traffic flow along major corridors. Moreover, by supporting cloud computing platforms, it is possible to store and analyze vast amounts of traffic data, which will provide the opportunity to study trends in the long term and design cities.

Such a system has its advantages that leave more than just short-term congestion control. Having the ability to gather and process constantly available data, the city officials can obtain information about the traffic behavior patterns and the peak time trends, as well as the zones with risk of an accident. Such lessons can be used when formulating future infrastructure projects like road upgrades or transport upgrades.

II. METHODOLOGY

There are several important steps of the creation of the Computer Vision Enabled Dynamic Traffic Light Control System: the data is gathered and preprocessed, then the objects are recognized, the traffic density is examined, and the real-time control of the signal is ensured. All these phases are significant towards precision, flexibility, and efficiency of the system.

2.1 Data Acquisition

The initial process is to collect real time video information of cameras that are placed at intersections. These cameras are mounted across multiple lanes within the junction to have a wide view of all the lanes in and out of the junction. Traffic analysis is mainly based on the video feed. The cameras are also set to record images under various lights and weather conditions to make them strong. This information is then sent to some central processing unit which can be an edge device or a cloud-based server, depending on the system architecture.

2.2 Preprocessing

Video raw data can be very noisy with different lighting, shadows and wind. In order to increase the precision of object identification, prechanging methods are used:

Noise Reduction: Gaussian and median filters will be applied to get rid of noise.

Frame Differencing: Frames (consecutive frames) are compared and this is used to determine moving objects. Background Subtraction: Background computer stuff is discarded thus making vehicles prominent. Normalization: Frame intensity is also adjusted to match the frame brightness under varied conditions of light.

2.3 Vehicle Detection and Classification.

The main idea in the system is the precise identification and categorization of vehicles in the lanes. This is done using deep learning algorithms that were trained using large datasets that contains images of cars, trucks, buses, and motorcycles. YOLO (You Only Look Once) algorithm is a real-time detection algorithm due to its speed and precision. YOLO classifies an entire image together as it predicts bounding boxes and class likelihood about the image. Faster R-CNN, on the other hand, can be used in cases where precision is more needed.

Every identified object is categorized as car, bike, bus or truck. Lane density is then calculated by use of the number of vehicles in each lane.

2.4 Signal Timing Optimization

Other things are also taken into account during the optimization process such as minimum and maximum time thresholds, pedestrian crossing time, and emergency vehicle recognition. Further reinforcement learning algorithms can improve the system learning the past data and also improve the future decision making.Emergency vehicle detection: Detection and classification of emergency vehicles (Sebra and Kekecs, 2009).

The system recognizes ambulances or fire trucks, which are emergency vehicles, using object recognition and sound analysis (through siren detection sensors). Once detected, the system automatically changes the relevant lane to green which guarantees a clear route.

2.5 Implementation of Control System.

The signal timings are sent to the traffic light controller through a microcontroller interface through optimization. Based on this, this controller can adjust the lights in real time. Processing units can also communicate with signal controllers through wireless networks or IoT-based communication protocols e.g. MQTT.

System Evaluation and Feedback Loop This step encompasses the evaluation of the system, facilitating the incorporation of the outcomes into the implementation process. <|human|>3.7 System Evaluation and Feedback Loop This activity involves the assessment of the system, which enables the integration of the results in the implementation process.

The system also has a feedback mechanism that is used to assess the efficiency of the traffic flow after every cycle in order to ensure that the system maintains accuracy. Continuous learning and performance analysis are done by logging data. Provided that some anomalies are detected, e.g., stalled cars or sensor malfunction, the system can generate alerts or go into the manual control mode.

The approach will achieve a data-driven, adaptable, and intelligent traffic light control system, which is able to act effectively to the changing circumstances and continuously enhance through the use of machine learning.

III. MOTIVATION

The intercity transportation infrastructures are under unprecedented pressure owing to spurt in population, rise in the number of individuals owning personal vehicles, and poor infrastructure development. The discrepancy between fixed signal systems and mobile traffic movement has led to congestion in most cities, environmental degradation as well as economic wasted potentials in most cities. Even the traditional traffic control techniques do not respond to the real-time situations that contribute to the inefficiencies which cause billions of lost productivity and fuel.

The impetus to come up with such a system is simply the dire need to have smart, efficient and sustainable solutions of traffic management. Computer vision and artificial intelligence allow an opportunity to modernize the aging infrastructure by automating the decision-making process and optimizing the use of resources. The proposed system will enable cities to react to real-time traffic trend dynamically instead of the use of pre-set timers.

In addition to efficiency in traffic, humanitarian and environmental issues are taken into consideration by the system. It prevents the emission of carbon and fuel used by reducing waiting times. Lifesaving capacities of identifying emergency cars and establishing priorities can be helpful in life-threatening situations. Moreover, the system may help provide useful data on initiatives associated with the urban planning and road safety.

Finally, it is driven by the inspiration of turning traditional cities into smart cities-places where technology is increasing quality of life through smart connected systems. This project will be a major step towards such a dream.

IV. ADVANTAGES

Real time adaptive control formed with the real traffic conditions.

- Longer travel time and fewer congestions.
- Reduced consumption of fuel and emissions.
- Priority of emergency vehicles is automated.
- Bigger and better fitted with smart city systems.
- Plays out analytical long-term data.

V. LIMITATIONS

Expenses of initial set up and installations are high.

- Supported by quality internet connectivity.
- Poor performance when it is raining or foggy.
- Calibration and maintenance of camera need to be frequent.
- Calculative delays may occur when the data load is large.

VI. APPLICATIONS

- Traffic management systems Smart cities.
- Highway and expressway highway control systems.
- Clearance of the emergency corridors.
- Prioritization of the use of public transport.
- Law enforcement and surveillance (e.g. red-light violations)

VII. CONCLUSION

The Computer Vision Enabled Dynamic Traffic Light Control System proves the unimaginable power of artificial intelligence and computer vision in addressing the actual challenge of urban mobility through this system. It can greatly enhance efficiency and improve traffic flow, cut down on emissions, and increase the safety of the general population by substituting area-stagnant, timer-driven systems with a real-time and adaptive control system. An intelligent system of decision-making will guarantee that any vehicle movement will lead to easier traffic flow and less time spent by standing in the queue.

This strategy can not only transform the urban transportation, but also conform to the objectives of sustainable development and smart city applications. Although it may have certain shortcomings, such as costly installation and reliance on the environment, the long-term payoffs such as fuel and air pollution savings, which would have improved emergency management in the city, make it worthwhile investing in this infrastructural facility in future urban architecture.

To sum up, the project shows that the combination of computer vision, machine learning, and internet of things can transform the city approach to traffic. With the increasing technological advancement, these systems will become invaluable in the achievement of safer, cleaning, and efficient urban transport systems throughout the world.

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