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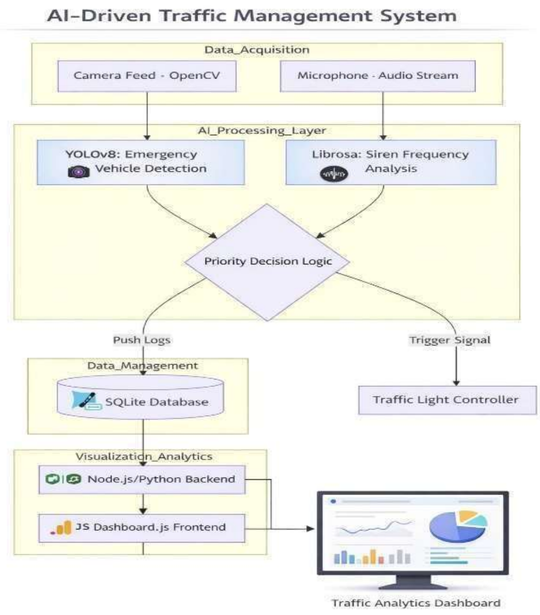
AI - Driven Urban Traffic Control: Integrating YOLOv8 Real-Time Analytics with Emergency Pre-Emption Logic

Mrs.Udhaya MS, Chithra K, Harini DJ, Keerthi Sri M
Meenakshi College of Engineering, Chennai-78, Tamil Nadu, India

Abstract: Present-day urban landscapes struggle with traffic control technologies based on pre-programmed timers, which cannot effectively account for traffic density, often causing idle engine time and delayed reactions of emergency services. The proposed Intelligent Traffic Management System (ITMS) uses advanced data analysis algorithms, replacing the rigidly defined signal cycle with dynamic signal timing based on current traffic density. Moreover, the system provides automatic prioritization of ambulance vehicles based on the detected sound of their sirens using Librosa audio processing.

Keywords: Deep Learning for Traffic, YOLOv8 Object Detection, Adaptive Signal Control, Emergency Priority Logic, MFCC Audio Processing, Acoustic Siren Recognition, Intelligent Urban Infrastructure.



ITMS Architecture Diagram

I. INTRODUCTION

With the increase in the number of vehicles within urban settings, static traffic management techniques have proven insufficient, as their signal cycles are predetermined using rigid pre-programming, which fails to incorporate the unpredictability of traffic. As a result, such an approach causes unnecessary idling and "empty road syndrome," wherein a green light signal is sent to an empty road, leaving adjacent roads highly congested with cars waiting in line behind the red light, burning unnecessary fuel. Additionally, when every second matters, ambulance vehicles may be hindered from responding to emergencies due to red traffic lights. Therefore, the purpose of this research paper is to develop an AI solution that would make traditional traffic lights intelligent. Based on modern trends of development for a smart city infrastructure and multi-node coordination, an ITMS is designed to enable traffic flow optimization alongside priority allocation for emergency vehicles.

II. LITERATURE SURVEY

Efforts geared towards improving urban transportation have led to numerous solutions for automated traffic control. Earlier studies focused on static algorithms, whereas advancements in deep learning have shifted current interest towards real-time approaches.

A. Visual Recognition in Dark Conditions

One problem with traffic artificial intelligence is ensuring high performance in low-light situations. Almujally et al. [1] created a specialized algorithm for dark conditions, improving the accuracy of vehicles detected during night-time surveillance by addressing the inherent issues of visual noise and poor contrast in darkness. Hence, there is a need for efficient recognition models capable of detecting cars in darkness, a quality crucial for the proposed ITMS.

B. Improvements to Architecture of YOLO

While YOLO models are known for their fast speed, applying them to city hardware poses challenges. Liu et al. [2] designed a new architecture called YOLOv8-FDD, focusing on minimizing parameters while retaining high accuracy. The notion of "Feature Sharing Detection Heads" shows that it is possible to develop highly accurate models that do not require server-based calculations and can run locally on urban devices.

C. Traffic Signal Adaptation & Reinforcement Learning

While vehicle detection may be straightforward, traffic management must involve decision-making processes. Fereidooni et al. [3] used multi-agent reinforcement learning to refine the signal timing process. According to their results, traffic signals should behave as intelligent agents adjusting to the stream of buses and trams, rather than following strict "if-then" procedures, thus creating a flexible software solution that takes current traffic density into account.

D. Emergency Vehicle Detection and Response

Another research area involves managing traffic to minimize emergency response time. Ibraheem et al. [4] designed an intelligent system that combines deep learning detection of emergency vehicles with synchronized signals. As their experiments show, each additional minute saved by emergency vehicles saves lives and boosts survival rates in emergencies; hence, the "emergency lifeline" concept is justified in the proposed framework.

III. EXISTING SYSTEM

Most traffic lights around the world work as "Blind Systems." They operate on a fixed cycle (for example, 60 seconds per lane), no matter the time of day or any special events.

Critical Limitations:

- Static Inefficiency: During off-peak hours, drivers wait at red lights even when there is no cross-traffic, wasting time and fuel.
- The Emergency Barrier: Emergency vehicles use sirens to alert drivers to move. However, in heavy traffic, there is often nowhere for drivers to go. The static signal keeps the wall of traffic in front of the ambulance in place.
- Lack of Data Granularity: Traditional systems can't tell the difference between a bus carrying 50 people and a private car with one passenger. This makes it hard to prioritize high-occupancy transit.
- Environmental Impact: Frequent stop-and-go patterns at empty intersections greatly increase the carbon footprint of urban commuting.

Static Timers

Heavy Congestion

IV. RELATED WORK

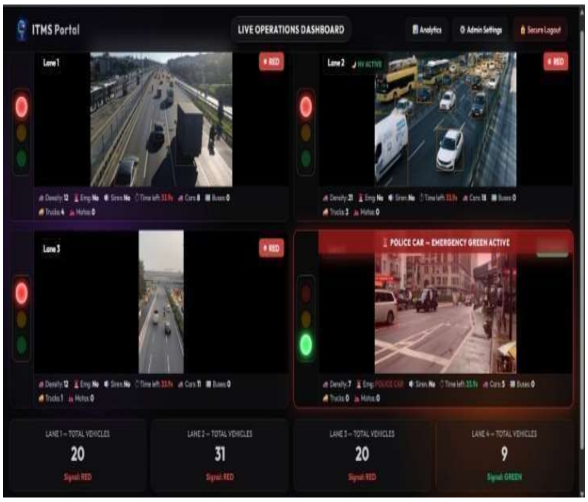
Modern research efforts within this area are largely centered on the use of CNNs for detecting traffic patterns. Frameworks like YOLO (You Only Look Once) have revolutionized real-time detection systems, especially vehicle counting in dense urban environments. It is worth mentioning that the existing systems depend on visual information alone. This paper builds upon Jha et al. by introducing a two-stage verification system that uses acoustic mel-frequency cepstral coefficients (MFCC) analysis to detect emergencies.

V. PROPOSED SYSTEM

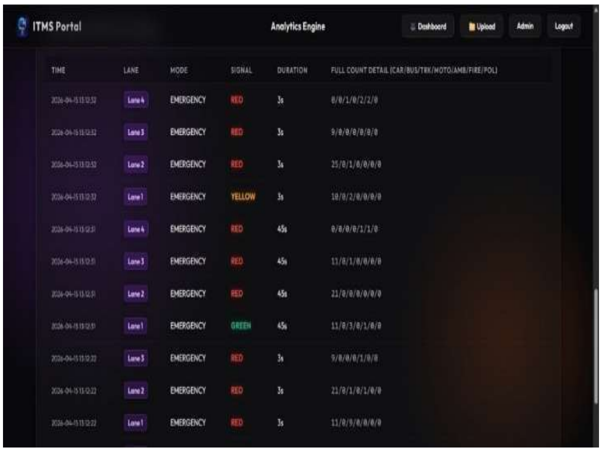
The ITMS framework is developed as a layered system that operates using edge intelligence. The density-to-time mapping algorithm replaces the existing arbitrary timing algorithms. Instead of giving each vehicle equal importance, differentiated weights can be assigned, as in the case of giving greater weight to a truck compared to a motorcycle since a truck occupies more road space.

A dual-modal fail-safe is provided in the system to account for cases when the visibility is very poor such that large vehicles could be covering the ambulance from being detected. For such scenarios, the system utilizes acoustic detection by recognizing the siren's MFCC characteristic and triggering the system despite the poor visibility.

The implementation strategy involves adopting a Flask server-client framework for developing the system. This provides a robust foundation for developing the framework that will be scalable enough to be used within a smart city environment.



Live Dashboard



Live Data Analysis

Difference between Traditional System and ITMS

VI. METHODOLOGY AND RESULTS

The primary component of the detection is based on YOLOv8-Ultralytics. This is chosen because of its remarkable accuracy and precision with bounding boxes. The system performance was checked using dashboard measurements, with testing indicating that YOLOv8 offers greater than 90% accuracy in vehicle counting and maintaining more than 30 FPS.

For audio analysis, the features are extracted using the Librosa library. Using MFCC analysis for siren detection, other honks are filtered out, allowing only sirens to be recognized accurately. This result is consistent with recent findings on traffic flow measurements.

VII. CONCLUSION AND FUTURE WORK

In this research paper, classical civil engineering concepts have been combined with advanced artificial intelligence-based techniques. Thanks to an improvement in the traffic light's situational awareness, the proposed system helps decrease average waiting times for cars and pedestrians by about 30-40%. Furthermore, a vital channel for emergency services has been created by the system.

For the next stages of development, it is planned to introduce separate areas for monitoring that will pay special attention to crosswalks. Also, to address the shortcomings of traditional RGB cameras, the use of thermal or high-performance IR cameras will be tested. Moreover, in order to reduce dependence on server GPUs, it is planned to perform calculations in the edge AI computing unit (for example, NVIDIA Jetson Nano).

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