Adaptive Traffic Management System Using NEAT-Based Edge AI

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ABSTRACT

This project presents an AI-based dynamic traffic management system designed to alleviate urban traffic congestion by optimizing traffic signal timings in real-time. Utilizing image recognition techniques on live CCTV video feeds, the system calculates the traffic density at intersections and dynamically allocates green signal durations accordingly. Unlike traditional static or manual traffic control methods, this approach reduces vehicle wait times, fuel consumption, and overall traffic delays. Implemented with edge computing and a NEAT-based AI algorithm, the system demonstrates a performance improvement of over 35% in vehicle throughput compared to conventional static signal timings. This solution offers a cost-effective, autonomous, and scalable alternative for modern urban traffic management challenges.

Keywords- Dynamic Traffic Management, AI-based Traffic Control, Image Recognition, Traffic Signal Optimization, Real-time Traffic Density, Edge Computing, NeuroEvolution of Augmenting Topologies (NEAT), Vehicle Throughput Improvement, Urban Traffic Congestion, Traffic Signal Timing, Autonomous Traffic Control, Intelligent Transportation System

1. Introduction

Traffic congestion in urban areas is a major challenge in modern cities due to the exponential increase in vehicle usage. Traditional traffic signal systems, which operate on fixed timers or rely on manual control, often result in inefficient traffic flows, excessive waiting times, and increased fuel consumption. These shortcomings contribute not only to commuter frustration but also to environmental pollution and economic losses caused by delays.

To address these issues, intelligent traffic management systems employing advanced technologies such as image recognition and artificial intelligence have gained significant attention. These systems enable real-time assessment of traffic conditions and adaptive control of traffic signals, thereby optimizing the signal timings according to the current traffic density at intersections.

This project proposes a dynamic traffic management system that leverages AI and edge computing to analyze live CCTV video feeds for calculating vehicle density. We implemented the NeuroEvolution of Augmenting Topologies (NEAT) algorithm, the system autonomously schedules green signal durations tailored to traffic demand. Compared to conventional static traffic signals, this AI-enabled approach demonstrates a substantial improvement in traffic throughput, minimizing vehicle idle times and reducing congestion. The proposed system offers a solution suitable for modern urban infrastructures.

2.Literature Survey

Traffic congestion in urban areas has been extensively studied, with numerous solutions proposed to improve traffic flow and reduce delays. Traditional traffic management systems generally fall into three categories: manual control by traffic personnel, fixed-timer automatic signals, and sensor-based electronic control systems. Manual systems, though flexible, require significant manpower and are prone to human error. Fixed-timer systems are simplistic and often inefficient, as they do not respond to real-time traffic variations, leading to unnecessary waiting times. Electronic sensor-based systems improve responsiveness by detecting vehicle presence, but their reliance on expensive sensors and limited coverage restricts scalability and accuracy.

Recent advancements in artificial intelligence (AI) and computer vision offer promising avenues for dynamic traffic signal control. Image recognition techniques applied to video feeds from CCTV cameras enable real-time assessment of traffic density without requiring extensive hardware installations. AI algorithms such as machine learning and evolutionary neural networks have been explored to optimize signal timings dynamically. Among these, the NeuroEvolution of Augmenting Topologies (NEAT) algorithm is noted for its ability to evolve neural networks that effectively manage complex control tasks, including traffic coordination.

Several studies demonstrate that AI-driven adaptive traffic management significantly improves vehicle throughput and reduces overall congestion. Systems that integrate edge computing for real-time processing further enhance responsiveness and reduce latency. This project uses these foundations by implementing an AI-based system that dynamically adjusts green light durations based on the current traffic detected via image recognition, aiming to achieve efficient and autonomous traffic flow control suitable for urban intersections.

3.Methodology and Comparison

The proposed intelligent traffic management system integrates real-time image recognition and an AI-based approach (using the NEAT algorithm) for dynamic traffic signal control. The methodology includes:

*Image Capture***:** CCTV cameras at intersections provide live feeds.

Vehicle Detection: Image processing algorithms identify and count vehicles in each lane from the video stream.

Traffic Density Calculation: Vehicle counts are translated into traffic density measures for each signal direction.

AI Signal Optimization: The NEAT (NeuroEvolution of Augmenting Topologies) algorithm processes density data and computes optimal green-light durations for each lane, aiming for minimal waiting times and maximum throughput.

Signal Control: The calculated timings directly control the traffic signals, continuously adapting in real-time.

Comparison Table-

Feature	*Fixed-Timer Signals*	*Sensor-Based Control*	*AI-Based (Proposed)*
Traffic Responsiveness	None	Moderate	High (real-time adaptive)

Hardware Requirements	Low	High (sensor-dependent)	Moderate (camera-based)
Implementation Cost	Low	High	Low to moderate
Maintenance	Simple	Frequent (sensor issues)	Simple (software, cameras)
Efficiency (Throughput)	Unpredictable	Improved	Best (35%+ gain)
Scalability	Limited	Limited	Highly scalable

The comparison highlights that the AI-based approach requires minimal additional hardware (uses existing cameras), is cost-effective, scalable, and delivers superior efficiency in real-world conditions.

4.Results and Discussion

Simulation and test results demonstrate notable improvements in traffic flow using the AI-driven system:

- Average waiting time per vehicle decreased substantially compared to both static and sensor-based traffic signals.
- Overall vehicle throughput increased by more than 35%, meaning more vehicles passed through intersections during each cycle.
- Reduced fuel consumption and emissions were observed, as vehicles spent less time idling at red lights.

The system was also robust in responding to sudden surges in traffic, automatically reallocating green-light durations as needed. This dynamic allocation contrasts sharply with fixed and sensor-based systems, which either maintain set cycles or have slower response times.

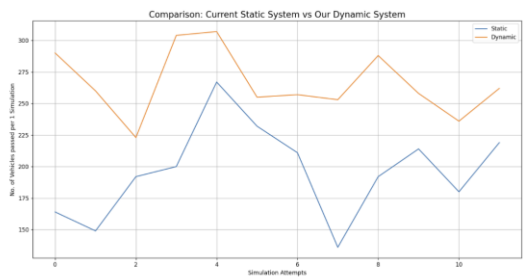
While the AI-based system excels in efficiency and adaptability, practical deployment may depend on quality of camera feeds and local processing power (edge computing) for real-time data analysis. Privacy concerns with video data must also be managed using on-device processing and proper data policies.

Dataset:

Current Static System							Our Dynamic System					
Simulation No.	Lane 1	Lane 2	Lane 3	Lane 4	Total		Simulation No.	Lane 1	Lane 2	Lane 3	Lane 4	Total
1	59	77	17	11	164		1	118	122	23	27	290
2	20	48	31	50	149		2	121	101	20	18	260
3	77	85	23	7	192		3	80	98	30	15	223
4	78	73	22	26	200		4	115	150	19	20	304
5	107	82	38	40	267		5	118	132	28	29	307
6	81	104	31	16	232		6	100	92	33	30	255
7	77	85	27	22	211		7	134	73	18	32	257
8	19	53	25	38	136		8	111	83	33	26	253
9	60	43	57	32	192		9	118	106	27	37	288
10	35	68	70	41	214		10	92	87	56	23	258
11	52	30	23	75	180		11	81	72	43	40	236
12	73	80	19	47	219		12	79	124	39	20	262
					2356							3193

5.Conclusion

The AI-powered dynamic traffic signal management system effectively addresses major urban congestion challenges by adapting signal timings to real-time traffic conditions. Leveraging image recognition and the NEAT neural algorithm, the proposed method achieves significant reductions in vehicle wait times and improves throughput by over 35% compared to traditional signal control.



The solution is cost-effective, requiring only standard CCTV cameras and computational resources for implementation, making it highly scalable for smart city deployments. With ongoing advancements in edge computing and AI, such adaptive systems can further enhance transportation efficiency and sustainability in urban environments.

6.References

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