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Real Time Traffic Congestion Management with AI & Arduino

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Abstract: Traffic congestion is a serious issue in modern cities. It causes delays, higher fuel consumption, air pollution, and stress for commuters. The main problem is traditional traffic light systems. They are inefficient because they use fixed, preset timers that cannot adjust to changing traffic conditions. This results in unnecessary waits on empty roads while other lanes are overcrowded. This project proposes an intelligent and adaptive Real-Time Traffic Management System. It will combine AI (Artificial Intelligence) and micro-controllers like Arduino. The main goals are to design a real-time system that uses AI to adjust signal timings based on live traffic. This should reduce congestion and waiting time at intersections. It will also implement a low-cost, efficient signal control system using Arduino. The proposed solution combines AI and Arduino to manage a four-way traffic intersection. The system uses a camera to capture live video, which is processed by a Python script using a Computer Vision (CV) model like YOLO or Open-CV. This script detects and classifies vehicles in real-time, calculating traffic density in each lane. The density data informs a Decision-Making Algorithm, and the timing changes are sent via Serial Communication (USB/UART) to an Arduino Uno that controls the LED traffic lights. The Literature Survey supports this approach, citing studies that highlight the success of deep-learning models like Efficient-Det and YOLOv8 in real-time traffic monitoring. These models achieve high counting accuracy (around 96%) and effectively reduce congestion while prioritizing emergency vehicles. The Expected Outcomes are promising. The system aims to produce a functional prototype, optimize traffic flow through dynamic signal timing, and reduce congestion and waiting times. Additional benefits include better efficiency, faster vehicle flow, and decreased fuel use. It will also enhance safety by prioritizing emergency vehicles and lowering environmental impact through reduced idling and carbon emissions. This AI-based system will adapt in real time and manage congestion much more effectively than traditional fixed-time methods.

Keywords: Traffic congestion, Artificial Intelligence, Arduino, Signal Timing Adjustment, YOLO/Open-CV, Adaptive Traffic Signal, Arduino, Vehicle detection, Traffic density Analysis, Computer Vision.

I. INTRODUCTION

Traffic congestion is a common and persistent problem in modern cities. This issue leads to significant delays for commuters, increased fuel consumption, more air pollution, and higher stress levels for drivers. The cause of this inefficiency often lies in traditional traffic control systems. Conventional traffic lights operate on fixed, preset timers. These schedules are often ineffective because they cannot adjust to changing traffic conditions. As a result, vehicles often wait unnecessarily on empty roads while nearby lanes are heavily congested. To address the limitations of fixed-time traffic management systems, a modern and adaptive solution is needed. Integrating Artificial Intelligence (AI) with micro-controllers, like Arduino, presents a promising way to solve this critical problem. This combination allows for the creation of a system that can quickly respond to live traffic data, providing a more effective control mechanism compared to fixed-timer systems. The proposed solution involves creating an Intelligent Traffic Management System that combines AI and Arduino to manage a four-way traffic intersection. The process begins with a camera capturing a live video feed of the intersection. A Python script on a host computer processes this feed using Computer Vision (CV) techniques, often applying models like YOLO (You Only Look Once) for real-time vehicle detection and classification.

This step is vital for accurately analyzing traffic density in each lane. The AI system's ability to determine real-time traffic density is crucial for its adaptive performance. After calculating the density, a decision-making algorithm sets the optimal timing for the traffic signals. This intelligence allows the system to go beyond fixed waiting times, creating a more flexible schedule. The traffic light control is managed by hardware that includes an ArduinoUno micro-controller. The AI model's decisions from the Python script communicate with the Arduino, typically through Serial Communication (USB/UART). The Arduino then implements the timing changes, controlling LED traffic signals to improve traffic flow. The primary goals of this project are to design a real-time traffic system that uses AI to adjust signal timings based on live traffic conditions, ultimately aiming to reduce congestion and minimize waiting times at intersections. Additionally, the system is designed to use Arduino as a cost-effective and efficient way to control signals in urban settings. The expected results of implementing this AI-based system are significant: it should optimize traffic flow through dynamic signal timing, greatly reducing congestion and wait times. This improvement leads to increased efficiency, allowing faster vehicle movement, shorter travel times, and lower fuel use. An AI-based system also enhances safety by prioritizing emergency vehicles, ensuring they experience no delays at signals. Finally, by cutting down idling time, the system is expected to reduce environmental impact, leading to lower carbon emissions and decreased air pollution.

II. LITERATURE SURVEY

The literature survey highlights several recent studies (2023-2024) exploring real-time, AI-based solutions for traffic management: The literature review shows that AI-driven solutions are effective. Recent studies feature systems using Raspberry Pi and Efficient-Det for deep-learning vehicle detection, which successfully reduced congestion, improved traffic flow, and prioritized emergency vehicles. Another study with YOLOv8 achieved a high accuracy of around 96% in real-time traffic monitoring. Machine Learning models have been successful in accurately predicting congestion, further improving signal control. These findings support the project's use of AI models like YOLO for dynamic control. Aarush Lathura (2023) reviewed technologies like RFID and VANETs for traffic monitoring. He proposed a smart system that uses sensors, AR, and edge computing. This system improved real-time control, reduced congestion, and increased energy efficiency. However, RFID and VANETs face challenges related to cost and power. M. Gupta, H. Miglani, P. Deo, A. Sameerchand Pudaruth, Irfaan M. Boodhun, and Choo Wou Onn (2024) used a Raspberry Pi with a camera and the Efficient-Det deep-learning model to detect vehicles, estimate density, and adjust signal timing. Their system reduced congestion, improved flow, and prioritized emergency vehicles effectively at a lower cost. They also developed a real-time system that uses YOLOv8 for detection, tracking, and counting, achieving about 96% counting accuracy. Trishita Das (2024) focused on predicting urban traffic congestion using a machine learning algorithm trained on sensor and app data. The model accurately predicted congestion and helped optimize traffic signals. MQ Kheder (2024) created a real-time traffic monitoring system based on IoT and robotics that uses deep learning (modified LeNet-5) for traffic sign recognition. This approach improved accuracy and efficiency in traffic monitoring and supports dynamic traffic management.

III. EXISTING SYSTEM

The traditional traffic management system is a major cause of urban traffic congestion. It mostly operates on a fixed-time schedule, using preset timers for traffic lights. The main problem with this approach is that it cannot respond to changing traffic conditions. Whether it's rush hour, an unexpected accident, or a quiet late-night period, the timing of the signals stays the same. This lack of flexibility results in significant inefficiencies: Unnecessary Waiting Time: Drivers often sit at a red light even when there are no cars on the intersecting road, which causes frustration and delays. Poor Congestion Handling: The system fails to adjust green light duration for busy lanes, making traffic jams worse. Inefficient Resource Use: The fixed timing leads to higher fuel consumption, increased stress for commuters, and more air pollution due to extended idling. In short, the traditional system is not smart. It acts as a simple timer and does not consider the current needs of traffic flow. The problem statement highlights the fixed-time schedule as the main issue, showing the need foran intelligent and adaptive traffic management solution to improve flow and reduce congestion. The proposed AI-based system tackles these problems by replacing the fixed schedule with a dynamic, real-time control mechanism.

IV. PROPOSED SYSTEM

The proposed solution presents an Intelligent Traffic Management System (ITMS) that addresses the issues of traditional, fixed-time traffic light systems. This ITMS combines Artificial Intelligence (AI) with an Arduino micro-controller to provide dynamic and adaptive control at a four-way traffic intersection. Its main goal is to adjust signal timings based on real-time traffic data, reducing congestion and waiting times.

System Architecture and Components

The system's design allows for a smooth process from data capture to signal execution, ensuring real-time responsiveness. Traffic Sensing (Data Acquisition): The system starts with a camera that captures a live video feed of the intersection. This camera serves as the main traffic sensor, continuously monitoring the flow of vehicles. AI Analysis and Density Calculation: The live video feed goes to a computer running a Python script. This script uses Computer Vision (CV) and an AI model, likely YOLO (You Only Look Once) or Open-CV, for detecting and classifying vehicles in each lane. The AI system conducts a density analysis, accurately determining the number of vehicles, or traffic density, in every direction of the intersection. This analysis is a critical step that turns raw video into usable traffic density data.

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Decision-Making Algorithm: After calculating traffic density, a Decision-Making Algorithm establishes the best signal timing for each light. Unlike a fixed timer, this algorithm assigns varying green light duration to the lanes with the most congestion, improving overall traffic flow. Signal Control and Execution: The AI script's decision must be implemented physically. Here, the Arduino Uno micro-controller acts as the low-cost, efficient signal controller. The density and timing information moves from the computer to the Arduino via Serial Communication (USB/UART). The Arduino directly manages the LED Traffic Signals, applying the timing changes right away. This final step guarantees a smooth traffic flow, as signals are adjusted in real-time based on current density.

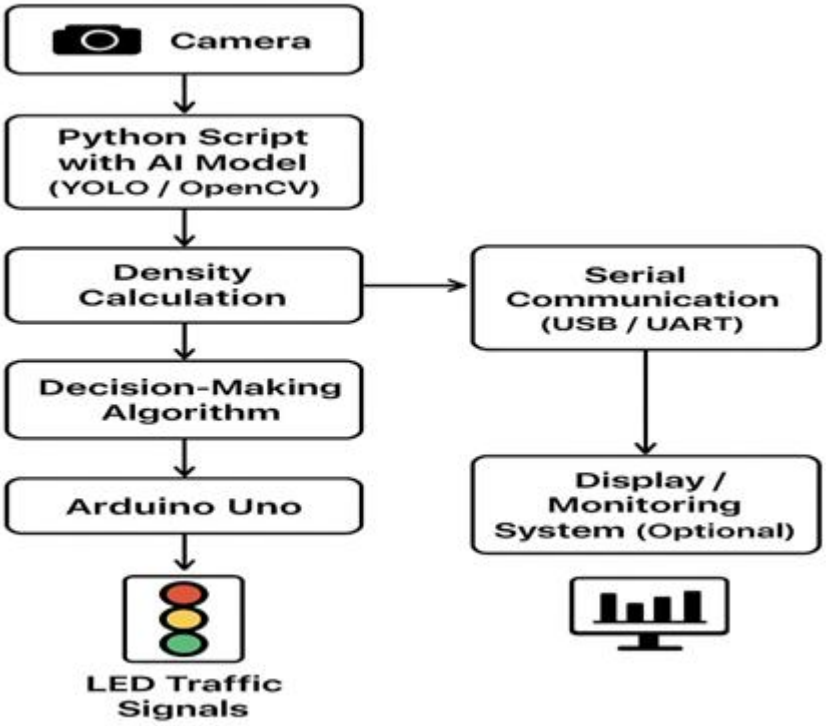

Fig.1 Flowgraph of working of real time traffic congestion management with AI and Arduino.

Technology Stack

1. Hardware Components

Microcontroller: Arduino Uno
Role: Acts as the primary signal controller. It executes the intelligent signal timing changes set by the AI script.
Sensing: Camera
Role: Captures the live video feed of the intersection, which serves as the real-time input for the AI system.
Output: LED Traffic Signals
Role: LED s simulate or represent the actual traffic lights, controlled directly by the Arduino Uno.

2. Software and AI Components

Programming Language: Python Script
Role: Runs on a computer to process the live video feed and includes the AI/Computer Vision model.
AI/Computer Vision Libraries:
YOLO (You Only Look Once) / Open-CV
Role: Used for real-time vehicle detection and classification in each lane to measure traffic density. This is the intelligence layer that replaces fixed timers.
Core Logic: Decision-Making Algorithm
Role: Determines the best signal timing based on the density calculated by the AI.

3. Communication Protocol

Protocol: Serial Communication (USB, UART)
Role: Enables communication and data transfer between the host computer running the Python/AI script and the Arduino Uno micro-controller. This connection is essential for executing intelligent decisions with the hardware. The integration of a computer running a Python script with AI (YOLO/Open-CV) for intelligence and an Arduino Uno for low-cost, efficient control forms the complete technological foundation of the adaptive traffic management system.

V.
VI. RESULT AND DISCUSSION

Comparison of Traditional vs. AI-Based Traffic Management

The main advantage of the AI-Based System is its ability to adapt dynamically, which addresses the strict limitations of the traditional approach.

Adaptivity:

The Traditional Arduino system does not adapt because it depends on fixed programming.

The AI-Based System responds in real time, allowing it to adjust quickly to changing traffic conditions.

Waiting Time:

Waiting times in the Traditional system are fixed.

The AI-Based System aims to reduce waiting times by managing green light duration more effectively.

Congestion Handling:

The Traditional system's ability to manage congestion is poor.

The AI-Based System handles congestion well since it can adjust signal timing to prioritize lanes with heavier traffic.

Lane Prioritization:

The Traditional system cannot prioritize lanes.

The AI-Based System can prioritize lanes, allowing it to give preference to emergency vehicles or lanes with high traffic.

Data Generation:

The Traditional system does not generate data.

The AI-Based System can produce data on vehicle counts, traffic density, and timing.The results confirm that combining AI with a low-cost micro-controller is a practical and effective solution for modern traffic management.

Optimized Traffic Flow and Efficiency

The most important outcome is optimized traffic flow. By calculating traffic density in real-time using the YOLO algorithm, the system changes control from a passive timer to a proactive scheduler. When a lane has high vehicle density, the decision-making algorithm automatically gives a longer green phase, while keeping minimum green time for low-density lanes. This quick adjustment reduces vehicle waiting time and increases vehicle throughput at intersections, directly addressing urban congestion.

Scalability and Cost-Effectiveness

The use of the Arduino Uno for signal control is a strategic choice for cost efficiency. Although the AI processing (Python/YOLO) requires a host computer, the signal switching is handled by affordable, sturdy, and easy-to-maintain hardware. This model is cost-effective enough to expand to multiple intersections, allowing for future integration into a broader smart city framework where adjacent traffic signals can coordinate their timing.

Environmental and Safety Benefits

The reduction in waiting time positively affects the environment. By decreasing vehicle idling, the system lowers fuel consumption, carbon emissions, and air pollution. Additionally, the smart system can improve safety by prioritizing emergency vehicles (e.g., ambulances, fire trucks) when detected, ensuring they do not face delays at signals—a feature traditional systems cannot consistently support.

VII. CONCLUSION

Dynamic Adaptivity. It replaces fixed timers with a real-time adaptive system, allowing signal timings to change based on live traffic density.

Optimized Flow and Efficiency. By adjusting the green light duration, the system improves traffic flow, which reduces congestion and waiting time. This leads to better efficiency with faster vehicle movement and shorter travel times.

Enhanced Safety and Sustainability. The system prioritizes emergency vehicles, eliminating delays for critical services. Additionally, reducing vehicle idling it lowers the environmental impact by decreasing carbon emissions and air pollution.

Scalability. Using low-cost hardware like the Arduino makes the system scalable. It can expand to larger intersections and integrate into smart city infrastructure.

In conclusion, this AI-based system is a working prototype that transforms traffic control from a rigid, inefficient process into a smart, data-driven solution. It shows significant potential for improving urban mobility, safety, and environmental quality.

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CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest related to the publication of this research paper. The study was done independently, and no financial, professional, or personal relationships affected the outcomes, interpretations, or conclusions in this work. All contributions were made only for academic and research purposes, aiming to improve knowledge in the field of Artificial Intelligence and Real-Time Traffic Management Solutions. The authors confirm that the research was conducted with full transparency, integrity, and respect for ethical standards.

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