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Ai Based Traffic Signal Coordination for Emergency Vehicles

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Abstract
These delays can affect emergency response time and create difficulties in reaching the required destination quickly. To address this problem, this research proposes an artificial intelligence-based traffic signal coordination framework that gives priority identifying their presence and adjusting traffic signal operations accordingly. The proposed approach combines the YOLO object detection model with OpenCV image processing, while SUMO (Simulation of Urban Mobility) is used to represent road net-works, vehicle movement, and traffic signal behaviour. It analysed to determine its position, direction of movement, and approaching intersection. Based on this information, the traffic signal can be adjusted dynamically through the Traffic Control Interface (TraCI) to provide a suitable passage. After the vehicle crosses the intersection, the normal traffic signal sequence is restored. The framework is intended to be evaluated using parameters such as emergency vehicle travel time, waiting time, intersection delay, vehicle queue length, and overall traffic flow. By combining computer vision, object detection, and traffic simulation, the proposed system provides a practical approach for studying intelligent emergency vehicle prioritisation and improving traffic signal coordination in urban road networks.

Keywords: Artificial Intelligence, Emergency Vehicle, Ambulance Detection, Traffic Signal Coordination, YOLO, Machine Learning, Real-Time Traffic Management, GPS.

1. Introduction

Traffic congestion in urban centers has evolved into a formidable impediment for contemporary transportation infrastructures, a challenge that is acutely exacerbated when emergency responders must navigate densely populated roadways. Ambulances, fire engines, and other critical response units frequently encounter significant obstructions at intersections, hampered by protracted vehicular queues and rigid, conventional traffic signal protocols. In such high-stakes scenarios, even a marginal delay can severely compromise the timeliness and efficacy of emergency service delivery. Consequently, the formulation of an intelligent framework for optimizing traffic signal management to ensure unimpeded passage for emergency vehicles has emerged as a paramount focus of current research endeavors.

Conventional traffic signal infrastructure typically functions on rigid, pre-established temporal schedules.While such a deterministic framework facilitates the orderly regulation of routine vehicular

flow, it frequently fails to adapt adequately to unforeseen exigencies, such as the incursion of an ambulance
navigating a congested junction. Neither manual intervention nor static signal programming possesses the requisite agility to accommodate the dynamic nature of evolving road conditions. Consequently, the implementation of an adaptive traffic control paradigm capable of detecting emergency vehicles and modulating signal phases in real-time offers a potent solution to this systemic inflexibility. Moreover, emergent advancements in artificial intelligence and computer vision have unlocked new possibilities for enhancing the precision and responsiveness of traffic monitoring systems. Within the proposed framework, the YOLO object detection model is employed to pinpoint emergency vehicles within image or video sequences, complemented by OpenCV for the extraction of pertinent visual data. This synergistic integration furnishes the essential visual intelligence necessary to ascertain whether an approaching emergency vehicle is on course to reach a traffic intersection.

Complementing SUMO, the Traffic Control Interface (TraCI) serves as the conduit for programmatic interaction with the simulated traffic ecosystem, enabling the dynamic adjustment of signal states. By synthesizing data derived from emergency vehicle detection—including precise location, trajectory, and proximity to upcoming intersections—the system computes an optimal signal response. Upon the successful traversal of an intersection by the emergency vehicle, the traffic signal reverts to its standard operational cycle.

The proposed methodology prioritizes the integration of real-time visual vehicle detection with dynamic signal management, moving beyond reliance on static, fixed-time operational schedules. The efficacy of this system will be assessed through key performance indicators, including emergency vehicle transit time, dwell time at signals, intersection delay metrics, queue dispersion, and aggregate traffic flow efficiency.

These quantitative parameters serve as the requisite benchmark for a rigorous comparative analysis between the proposed adaptive approach and traditional signal control mechanisms.

This study advances intelligent transportation management through a simulation-centric methodology that integrates YOLO, OpenCV, SUMO, and TraCI.

The proposed framework is designed to facilitate deeper inquiry into the realms of automated emergency vehicle detection and the synchronized regulation of traffic signals. Furthermore, it establishes a robust foundation for subsequent developments, including the incorporation of real-time camera surveillance, GPS-enabled vehicle tracking, and seamless bidirectional communication protocols between emergency responders and traffic infrastructure.

2. Objectives

1. **Real-Time Emergency Vehicle Detection:** To develop an AI-based approach using YOLO object detection to identify emergency vehicles, particularly ambulances, from traffic images or video frames.
2. **Traffic and Route Analysis:** To analyze emergency vehicle movement, intersection locations, and surrounding traffic conditions to determine appropriate signal-control decisions.
3. **Reduction of Emergency Vehicle Delay:** To evaluate the potential of dynamic signal coordination to reduce emergency vehicle waiting time and intersection delays compared with conventional fixed-time traffic signals.
4. **Simulation-Based Performance Evaluation:** To assess the proposed approach using SUMO simulation and performance indicators such as travel time, waiting time, queue length, intersection delay, and overall traffic flow.

3. Scopes

This research delineates the development of a simulation-driven framework designed to facilitate intelligent traffic signal coordination, thereby optimizing the transit of emergency vehicles through complex urban road networks.

Utilizing the TraCI interface, the system dynamically computes the requisite traffic signal adjustments by analyzing the detected vehicle's precise location and trajectory. The investigation rigorously evaluates key performance metrics, encompassing emergency vehicle travel duration, signal waiting periods, intersection delays, queue accumulation, and the aggregate efficiency of traffic flow. This proposed investigation is confined to a simulated environment, with its primary objective being the assessment of emergency vehicle prioritization schemes in contrast to traditional fixed-time traffic signal operations.

1. The system is dedicated to the identification of emergency vehicles, with a specific emphasis on ambulances, by leveraging YOLO-based object detection algorithms applied to traffic imagery or video frames.
2. The framework is designed for future scalability, capable of integrating GPS-based tracking, IoT communication protocols, real-time CCTV surveillance, and multi-intersection coordination to comprehensively support green corridor management.

At present, the scope of this investigation is confined predominantly to simulation-driven development and assessment.

4. Needs

The proposed system aims to improve emergency vehicle movement by detecting ambulances using AI-based techniques and coordinating traffic signals dynamically. It focuses on reducing emergency vehicle waiting time, managing traffic congestion, and evaluating system performance through SUMO simulation. The framework can be extended in the future using GPS, IoT, and multi-intersection coordination for smart city traffic management.

5. Literature Survey

Previous research has investigated several approaches to emergency vehicle prioritization at signalized intersections. These approaches include computer vision, machine learning, vehicle-to-infrastructure communication, Internet of Things (IoT), and traffic simulation. The following studies are relevant to the development of an AI-based traffic signal coordination system.

1. Queue Discharge-Based Emergency Vehicle Traffic Signal Preemption (2020)

The approach was evaluated through SUMO simulations and verified using real urban traffic experiments. Its main contribution is the consideration of actual queue conditions when deciding when to activate signal priority, helping reduce unnecessary disruption to other traffic.

2. YOLO-Based Emergency Vehicle Detection and Signal Control

These approaches demonstrate the potential of combining computer vision with automated signal control. However, detection reliability under different lighting conditions, partial occlusion, and dense traffic remains an important consideration.

3. IoT-Enabled Radius-Based Traffic Signal Preemption

An IoT-enabled radius-based framework proposes using GPS-equipped ambulances, roadside units, edge traffic controllers, and cloud-based monitoring to identify emergency vehicles approaching intersections. The system uses a predefined proximity threshold to trigger signal preemption and provide a green signal

along the required route. This approach highlights the importance of real-time communication and location-based priority management in smart-city transportation systems.

4. Machine-Learning-Based Emergency Vehicle Preemption

Research on machine-learning-based emergency vehicle preemption has investigated the use of real-time vehicle detections, traffic signal indications, and emergency vehicle locations to determine suitable preemption timings at multiple downstream intersections. The method formulates signal-priority timing as a prediction problem and uses traffic simulation data to develop and evaluate the model. Such approaches aim to reduce emergency vehicle travel time while limiting delays to conflicting traffic movements .

5. AI-Based Emergency-Aware Adaptive Traffic Signal Control (2026)

A recent study integrated YOLO-based emergency light-bar detection with an optimized traffic signal controller and evaluated the framework using SUMO simulation. The reported results showed improvements in ambulance travel time and waiting time compared with conventional fixed-time and optimized traffic-control strategies in the selected simulation scenario. The study demonstrates the potential of combining visual emergency detection with adaptive traffic signal management.

Research Gap: Existing studies demonstrate the potential of visual detection, GPS-based communication, queue-aware control, and machine-learning-based signal preemption. However, further investigation signal coordination, and systematic performance. The present research focuses on these components and aims to assess the proposed approach using emergency vehicle travel time, intersection delay, waiting time, queue length, and overall traffic flow.

6. Proposed Methodology

The proposed methodology focuses on developing an AI-based traffic signal coordination system for emergency vehicles using YOLO-based object detection and SUMO traffic simulation. Initially, a simulated urban road network is created using SUMO, consisting of roads, traffic intersections, normal vehicles, and emergency vehicles. Traffic data and simulated video frames are processed using OpenCV to prepare suitable inputs for emergency vehicle detection. The YOLO model is then used to identify emergency vehicles and determine their positions and movements. Based on the detected vehicle's location, direction, and approaching intersection, the system analyzes the required traffic signal and generates an appropriate control decision. The signal corresponding to the emergency vehicle's route is given priority while conflicting traffic movements are temporarily restricted. After the emergency vehicle passes the intersection.

7. System Architecture And Algorithm

7.1 System Architecture

The proposed system architecture integrates AI-based emergency vehicle detection, traffic analysis, and dynamic traffic signal control within a SUMO-based simulation environment.

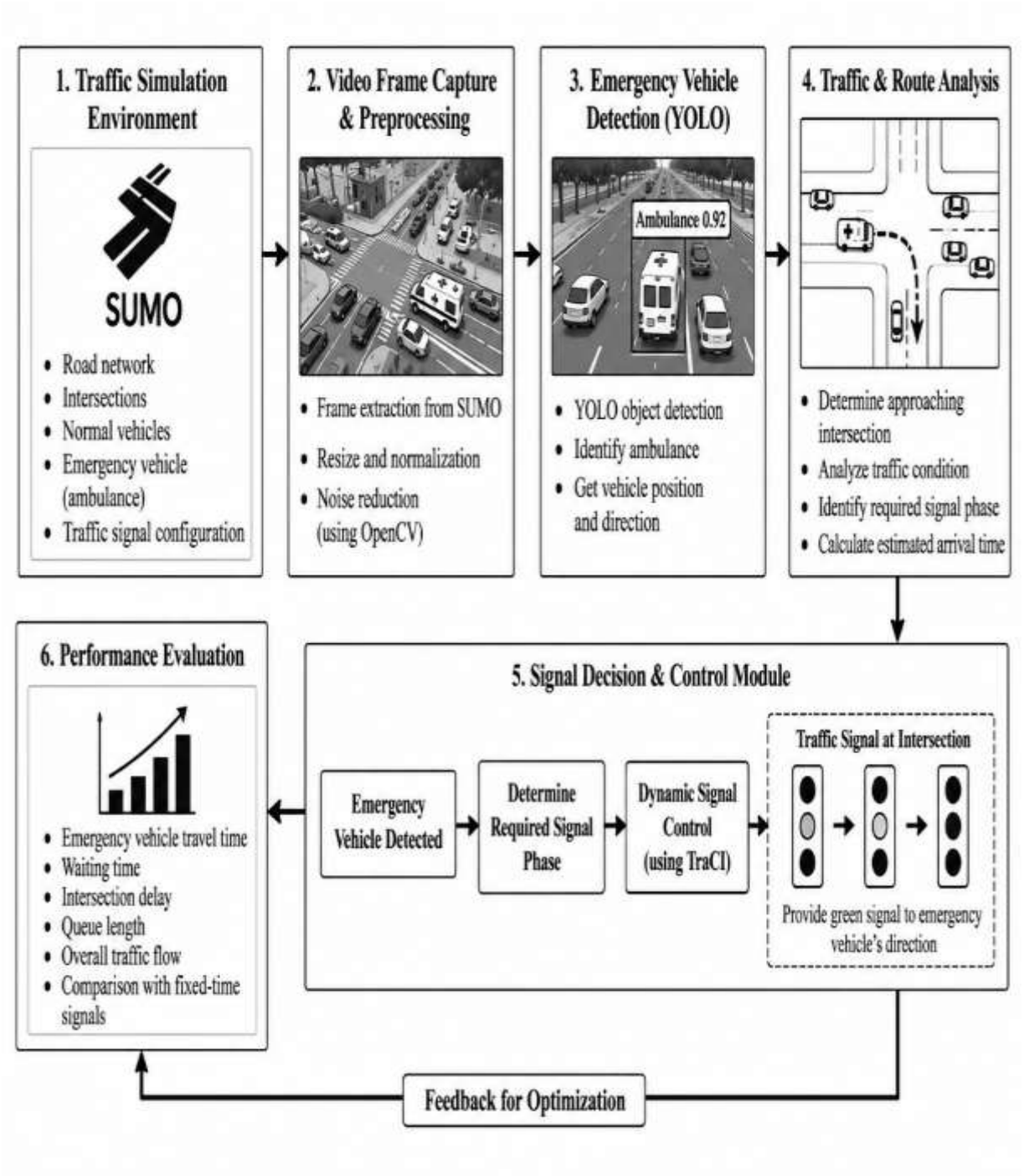


Fig1:- Proposed system architecture for emergency-vehicle detection, route prioritization and coordinated signal control.

7.2 Flow Chart/Algorithm

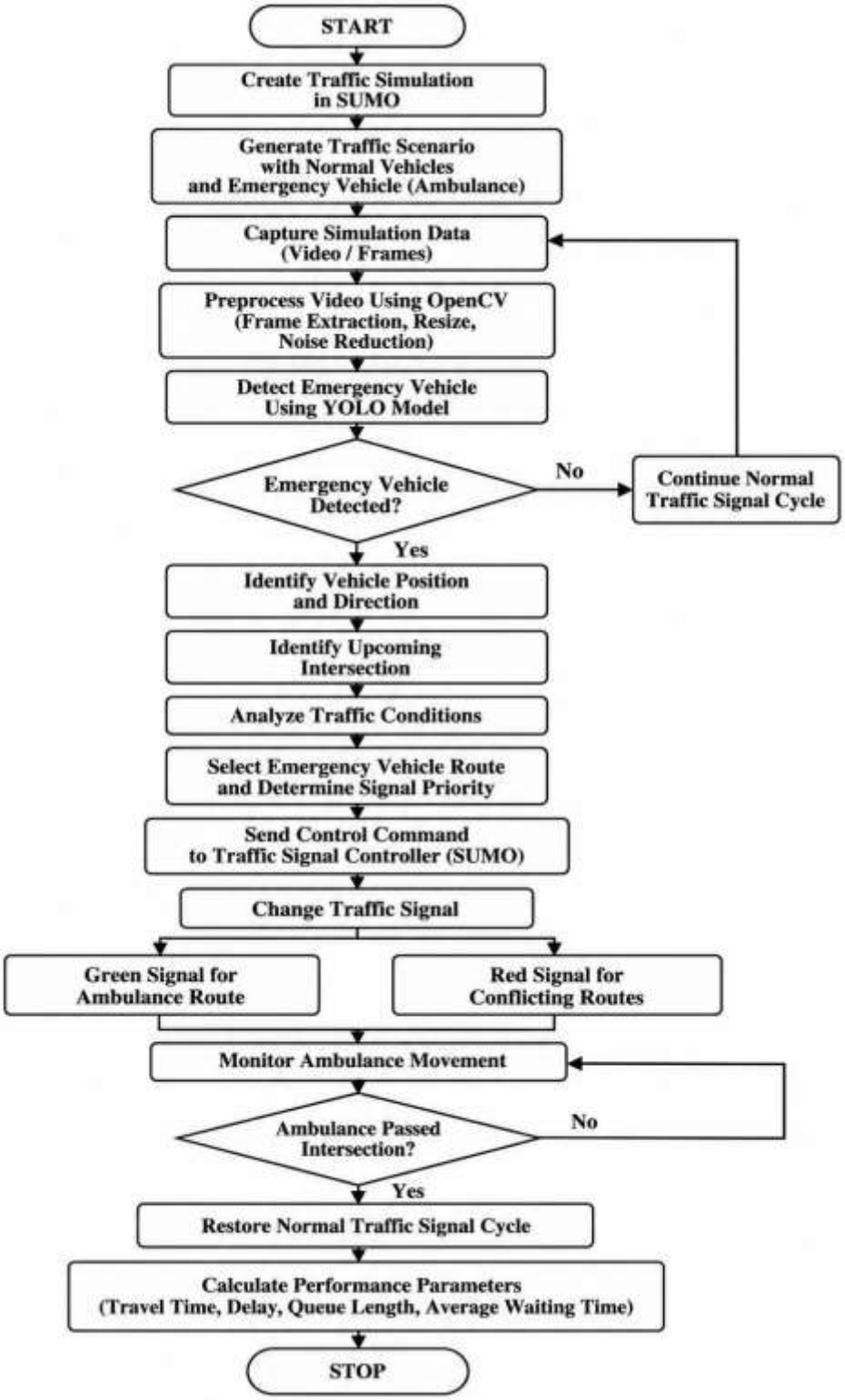


Fig2:- algorithm

8. Simulation Environment and Experimental Setup

TraCI provides a programmatic interface through which an external Python controller can read simulation state and modify supported signal or vehicle parameters. The network may be created from

a small grid or a real road extract; for a final-year project, a corridor with several consecutive signalized intersections is sufficient to demonstrate green-corridor coordination.

9. Acknowledgement

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10. Results and Discussion

The system aims to identify approaching emergency vehicles, analyze their movement, and dynamically control traffic signals to provide priority along the required route.

The simulation-based framework provides a controlled environment for examining emergency vehicle priority under varying traffic densities and intersection conditions. However, the actual effectiveness of the proposed approach must be established through implementation and experimental testing. Since the current project report does not provide measured simulation results or a quantitative comparison, specific improvements in travel time, detection accuracy, or traffic efficiency cannot yet be confirmed.

11. Conclusion

This research presents an AI-based traffic signal coordination framework for emergency vehicles to address delays caused by traffic congestion at urban intersections. The proposed system integrates YOLO-based emergency vehicle detection, OpenCV-based image preprocessing, SUMO traffic simulation, and dynamic traffic signal control using TraCI. The system also provides a simulation-based approach for evaluating performance using parameters such as emergency vehicle travel time, queue length, intersection delay, and overall traffic flow. Although the proposed framework offers a potential solution for intelligent emergency traffic management, its effectiveness must be confirmed through implementation and quantitative experimental evaluation. Future enhancements may include GPS integration, IoT communication, real-time CCTV monitoring, and coordination across multiple intersections to support green corridor management in smart cities.

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