Detection and Prioritizing for Emergency Vehicle Using Deep Learning

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***Abstract*—Emergency vehicle detection systems become optimized by implementing deep learning and visual sensing as part of this project. Emergency vehicles get faster responses through real-time detection that changes traffic light priority to give vehicles priority status. The system evaluates traffic flow to develop open emergency vehicle paths that reduce travel delays. The system develops increased effectiveness through time by using ongoing traffic data learning that lets it adjust to evolving surroundings. A united response to emergencies with optimized efficiency will happen through full integration of this system into current traffic management networks. Urgent management of urban traffic and emergency response functions alongside public safety improvements result from this system that provides precise routing for vehicles.**

***Index Terms*—Deep Learning, Visual Sensing, Emergency Response Systems, Real-Time Detection, Traffic Management, Emergency Vehicle Detection, Dynamic Traffic Control.**

I. INTRODUCTION

Emergency services benefit from a newly proposed traffic management system that minimizes delays created by traffic congestion in their operations. As urban populations expand it becomes inevitable that traffic density will increase hence the control of emergency vehicle routes has become difficult for prompt critical delivery.

Emergency vehicle priority at intersections gets possible with visual sensing technology and Wi-Fi modules which results in faster response and increased safety for the public. This system includes an ESP module together with a camera and LED traffic signals along with a QR code and buzzer positioned at the first intersection. Monitoring activity in the intersection area relies mainly on camera and visual sensors that function to detect approaching emergency services on time. This system detects emergency vehicles upon their arrival so it activates the LED signal through modified traffic signals that enable the vehicle to cross the intersection without any delay. Traffic safety improves through both the QR code combined with buzzer system to offer alerts to vehicles and pedestrians.

The system optimizes traffic signal control to reduce emergency response time and increases the effectiveness of services dealing with life-threatening emergencies. The beneficial impact of this approach because it streamlines operations that reduce the probability of dangerous traffic accidents while enhancing safety standards across the community.

This proposed solution can integrate with existing urban traffic management platforms in order to become a cost-effective choice for cities focused on emergency response improvements. Current emergency services face a major challenge for which visual sensing and Wi-Fi technology combined with real-time data processing delivers a reliable smart solution. The system has the potential to detect emergencies more quickly which could save lives together with improving the operational effectiveness of emergency teams in busy urban battlefields.

The integration with present infrastructure leads to decreased operational disturbances as it boosts emergency service effectiveness. The system uses processing of real-time data along with intelligent traffic signal control which enables it to adjust operational systems to traffic changes giving emergency vehicles priority access regardless of peak congestion. Urban public safety benefits significantly because this innovative solution enhances both traffic optimization programs and smaller emergency response times in city spaces. This solution can expand to cities worldwide because of its flexibility which enables comprehensive implementation to enhance emergency service and traffic cooperation thereby saving lives in urban environments.

The framework implements Pathway to conduct real-time document indexing and Mistral 7B executes context-sensitive response generation through an Ollama local interface using internal data resources. A unified vector store through Pathway enables fast retrieval of relevant content from multiple sources which exactly meets the context requirements of the LLM. The platform prevents data from exiting its protected space at any time throughout operation.

The architecture implements a dynamic retrieval mechanism which enables high performance while maintaining all regulations and control measures. The solution obeys privacy laws together with business governance criteria to enable responsible AI deployment.

Overall, this paper proposes a secure, scalable stack of RAG appropriate for balancing trust, performance, and AI strength in sensitive enterprise environments.

Further, the paper is illustrated as follows: The related work is discussed in Section II. Problem definition is elaborated in Section III. The proposed work is described in Section IV. Novelty of proposed work is presented in Section V. Results of the proposed work is depicted in Section VI. Conclusion and future enhancements are discussed in Section VII.

II. EASE OF USE

Simple and efficient recognition of emergency vehicles in urban traffic operates through the YOLO (You Only Look Once) object detection algorithm. YOLO combines its object classification together with bounding box prediction in just one run instead of multiple stages thus enabling reduced processing time and higher system speed. Since YOLOv5 implemented advanced methods for accuracy enhancement and speed optimization it demonstrates the best functionality for real-time traffic management systems. YOLO uses one-stage detection architecture to perform direct regression without needing region proposal. The model accepts full-frame inputs during operations while directly generating bounding boxes with classification scores so that real-time performance reaches its peak.

Key Strengths in Traffic Scenarios

The system operates with maximum speed because it identifies objects in its first processing cycle. This system demonstrates resistance to various lighting conditions and to complete and partial vehicle blockages while operating on different vehicle dimensions.

The detection abilities for small or hidden emergency vehicles improve when YOLO-based systems utilize enhanced feature combination techniques in busy urban traffic conditions. The research paper Emergency Vehicle Detection Using YOLOv5 (2022) by Sharma & Mehta demonstrated effective results.

real-time traffic management frameworks.

YOLO-Based Traffic Detection Breakthroughs

A. *Case Study: Emergency Vehicle Detection Using YOLOv5 (2022) – Sharma & Mehta :*

Sharma and Mehta (2022) effectively used The research of Sharma and Mehta (2022) achieved emergency vehicle detection success in urban settings using YOLOv5 with an ambulance and fire engine detection accuracy of 89.4% precision. The researchers utilized edge-based filtering to achieve higher accuracy rates within heavily crowded locations during their study. Small vehicles detected with difficulty from distant locations during night conditions required attention-based enhancement of detection accuracy according to the researchers.

B. *Hybrid Technique: YOLOv7 with Graph Neural Networks (GNNs) for Traffic Regulation (2023) – Patel et al.*

Patel et al. (2023) developed YOLOv7 + Graph Neural Network (GNN) technology which enhanced traffic detection robustness in dense areas at the cost of extensive computer usage thus making it unfit for widespread real-time applications.

C. *EL-YOLO: Efficient Emergency Vehicle Detection (2023)*

The innovative extension of YOLOv8 in its current version is known as EL-YOLO. The Shortcut Multi-Fuse Neck (SMFN) feature enhances multi-scale feature learning to achieve better detection of small and moving vehicles. AWIoU elevates bounding box precision to better detect emergency vehicles during locations.

D. Improving Detection in Low-Visibility Conditions (2023)

The authors combined super-resolution techniques with YOLOv5 to enhance emergency vehicle detection accuracy in low-light situations during night time or fog conditions through their 2023 paper. By applying this enhancement method images received better quality which boosted detection accuracy by 12% relative to standard YOLO implementations.

E. Real-Time Tracking with Temporal Consistency (2024) – Zhang et al.

Zhang et al. (2024) tackled the weaknesses of advanced YOLO multi-frame vehicle tracking by adding temporal consistency models to rectify its weaknesses. By performing this method tracking stability improved between consecutive frames while it reduced detection errors which arose from changing traffic conditions and obstructed views. The system's implementation needed powerful processors to operate in real time because of its demanding computational needs.

F. Performance Evaluation Metrics

The following essential measures assess emergency vehicle detection system precision and dependability:

The detection of emergency vehicles properly constitutes True Positives (TPs).

Proper emergency vehicle detection results happen when they detect non-emergency vehicles as emergency vehicles (False Positives).

False Negatives (FN) – Missed emergency vehicles.

$$Precision = \frac{TP}{TP + FP}$$

$$Accuracy = \frac{TP + TN}{TP + FP + FN + TN}$$

III. LITERATURE SURVEY

The literature review shows recent academic studies between 2016 and 2024 focus on improving traffic systems by giving emergency vehicles top priority in urban settings through deep learning technology and visual sensing and acoustic detection alongside Internet of Vehicles (IoV) systems which demonstrate various solutions and problems for emergency vehicle real-time prioritization.

The researchers have conducted a highly relevant examination of deep learning adoption for vehicle detection and tracking which enhances traffic management operations. Higher accuracy levels characterize deep learning as the most vital instrument for spotting urgent vehicles navigating through busy roads. The researchers explain that deep learning algorithms demand large amounts of computational resources so they become problematic for systems with limited processing capabilities. By optimizing deep learning systems their team aims to reduce system requirements for computation so the systems can be implemented on a large scale within urban areas.

Visual sensors linked with deep learning are examined in the 2016 study to establish emergency vehicle traffic priorities at intersections. The traffic management system modifies real-time traffic light signal patterns to ensure better emergency vehicle movement. Visual sensors function optimally only when conditions do not depend on the surrounding environment because they become ineffective under conditions like fog or rain or at night. Additional sensor technologies implementing infrared sensing along with acoustic detection would address these system limitations according to the authors who want to enhance overall robustness.

Ahsan Shabbir (2023) provides an alternate detection method which depends on acoustic signals. The hearing ability of acoustic detection becomes ideal for situations where visual systems stop functioning due to conditions like fog or nighttime. The detection method provides dependable results while poor visibility prevails but urban background disturbances reduce its precision levels. The authors argue that detecting targets with an acoustic detection system linked to visual sensing improves recognition under diverse operational conditions.

The 2017 research investigates how Internet of Vehicles technology can optimize routes for emergency vehicles in priority selection of road traffic networks in emergency situations based on internet of vehicles (2017). Real-time vehicle infrastructure communication through IoV makes it possible to update emergency vehicle routes according to the active traffic situation. Real-time route optimization allows this technology to grant emergency vehicles much better priority status. The study reveals that cities might hesitant to adopt IoT because of its expensive implementation costs. Future work will concentrate on cost-reduction efforts or IoV integration with other technologies for making access and cost-effectiveness better.

The update in deep learning-based vehicle detection for traffic management enables superior detection of vehicles with the help of deep learning technology. This method enhances both detection accuracy and speed for emergency vehicles even though it does not focus on them specifically. The system requires improvements for efficient performance in scenarios with limited computational power demonstrating the need for optimization.

Researchers have developed deep Q- Learning (2024) which uses reinforcement learning specifically Deep Q-Learning to manage traffic movements of emergency vehicles. Emergency vehicles will traverse the fastest routes because this AI-controlled traffic management system constantly optimizes the surrounding road conditions. The implementation of this approach demands big training samples and powerful processing resources which create obstacles for practical deployments. For enhanced implementation of the system researchers must focus on optimizing its performance while decreasing its dependence on extensive data storage requirements.

Researchers have discovered that emergency vehicle detection becomes more effective through multimodal fusion of video and audio data in “Another Relevant Study Enhancing Emergency Vehicle Detection: A Deep Learning Approach with Multimodal Fusion”. When multiple sensory inputs fuse together for detection security and performance surpasses operations that use single-input systems. The system requires large data processing together with sophisticated technology while researchers must spend more effort to optimize it for real-time usage in heavily populated urban spaces.

Visual Sensing Technology Directed to Emergency Vehicles in Traffic Control Systems forms the basis of research for 2023. The promising system encounters specific limitations regarding environmental factors. The system requires infrared and acoustic sensors according to the authors to enhance performance during harsh weather and low light situations.

Multiple investigated studies demonstrate how deep learning together with visual sensing and acoustic detection alongside IoV systems effectively solve urban traffic management problems by setting emergency vehicles as a priority. Each within its own strengths generates operational barriers alongside computational needs and environmental conditions and infrastructure expenditures. Research moving forward should combine technological devices into single systems to resolve diverse conditions and cut implementation expenses and boost emergency vehicle prioritization performance. The resolution of these problems will enable better control of traffic patterns and speed-up emergency vehicle response durations while creating better security conditions for urban areas.

IV. OBJECTIVES

a) Real-Time Emergency Vehicle Detection

Emergency vehicles get identified in real time through a system that operates YOLO for object detection. Emergency services receive quick priority at intersections due to this detection method hence enabling faster emergency route clearance with shorter delays and safer roads.

b) Robust Detection Across Different Conditions

The YOLO model excels at identifying emergency vehicles of diverse sizes with various colors and orientations regardless of heavy urban conditions. It works well under:

Heavy traffic – Distinguishes emergency vehicles amidst crowded road networks.

Emergency vehicle pick-ups perform adequately in conditions marked by darkness or minimal external illumination.

YOLO identifies emergency vehicles from different directions regardless of partial obstruction from road traffic or city features.

c) Scalable and Real-Time Traffic Management

Due to its quick inference speed YOLO delivers the capability for large-scale deployment across city streets and at different intersections. Large amounts of data from multiple traffic cameras are processed effectively by the model which establishes it as an optimal solution for emergency vehicle monitoring within smart cities.

d) Performance under Complex Traffic Situations

The detection system functions optimally under difficult environment conditions that include:

The system functions correctly during conditions of snowfall and rain along with foggy weather conditions.
High congestion – Sustaining correct detection even in busy roads.
The system allows emergency vehicles to achieve rapid identification while moving at high speeds through vehicles.

e) Unified and Efficient Detection Model

YOLO implements its one-stage neural network framework to perform a direct detection of emergency vehicles and their recognition through a single processing cycle. The model no longer demands independent steps for region proposal because it results in direct benefits of:
The system delivers rapid information processing which benefits real-time traffic management operations.
Enhanced detection precision – Minimizing false negatives and positives.
Better decision-making – Facilitating timely signal adjustments for emergency routes.

f) Advanced Image Processing for Better Accuracy

The system adds better image processing techniques to detection accuracy as a supplemental measure. By improving the resolution quality through super-resolution algorithms, the system receives better images which aid vehicle detection. Background subtraction – Separating emergency vehicles from dynamic cityscapes. Optical flow analysis enables the system to correctly identify standard traffic vehicles alongside emergency responders through tracking vehicle activities.

V. PROBLEM IDENTIFICATION

Emergency vehicle priority in traffic management faces strong challenges because urban congestion worsens due to current ineffective systems and insufficient adaptive technological solutions. The limited adaptive capabilities of fixed signals block both emergency responders and ambulance and fire trucks because signals cannot make automated changes. Modern communication systems use sirens alongside radio signals yet these methods become inaudible amid excessive noise pollution or heavy vehicle density. The sequence of emergency unit dispatch is extended by multiple factors leading to disastrous results including fatalities and damaged property.

The combination of AI-based traffic management with the current modern visual sensing technologies presents the essential challenge. The current emergency response vehicles rely on outdated traffic management systems and manual driver assistance through which delays and inaccuracies occur frequently. Static traffic flow systems create obstacles that prevent emergency vehicles from taking shortcuts through the urban area. Modern urban road networks experience persistent growth in complexity thus requiring technology intervention for any city navigation attempt.

Systems for traffic management that rely on visual sensing must become indispensable since they provide answers to today's problems. Using cameras and computer vision models, emergency vehicles can be automatically recognised in real-time. This enables them to receive advantageous signal adjustments and mathematical traffic distribution to vehicles for more efficient transportation. This methodology makes it possible to create a traffic-adapted process that needs little human intervention. IoT traffic systems and highly developed AI programs allow for quicker responses that better complement the components of the current infrastructure.

VI. PROPOSED METHOD

An advanced system for managing emergency priorities in addition to standard traffic distribution is a deep learning-based traffic management platform that is ready for deployment. Together with real-time signal modification capabilities for traffic regulation, this functionality enables real-time recognition. By taking these steps, emergency response operations will be enhanced and everyone else using the road will be safe. The suggested methodology is as follows.

i. The deep learning algorithms with CNNs function to analyze live video streams for detecting emergency vehicles which then leads to path clearing.
ii. A deep learning system controls traffic signal durations by monitoring both emergency vehicle speed and distance towards intersections.

iii. The analysis of predictive traffic flow allows the system to warn about traffic jams using models which control traffic lights for better network efficiency.
iv. Through deep learning the PE-MAC protocol receives optimization for better communication between vehicles and Traffic Management Centre.
v. Better road safety emerges from the automated system which provides emergency vehicles with priority status while optimizing traffic system operations.

VII. ARCHITECTURE

a) Frontend: User Interface

Technologies Used: HTML, CSS, Bootstrap, JavaScript.

The interface gives users an interactive tool for traffic data management along with emergency vehicle priority control.

Roles and Responsibilities:

Such responsibilities of the administrator include setting traffic system parameters as well as monitoring system performance.

Traffic operators maintain monitoring of ongoing traffic feeds as well as detect emergency vehicles before they control the flow of traffic manually if needed.

System users search through traffic data visualization elements to develop better decisions.

b) Backend: Flask Framework

As the final backend API server, the framework allows frontend-user system communication through its processing role.

The system responds to the user interface when the interface requests information about detected vehicles and traffic signal statuses.

The system receives video input that enables real-time detection results to be incorporated into the database.

The API manages all routes that access vehicle logs alongside signal adjustment functionalities and system setup functions.

c) Data Storage: MongoDB

Type: Centralized cloud database. The database achieves secure storage of detection logs together with vehicle information combined with traffic signal states while maintaining system configuration data.

Structure:

Collections: Include data for the system stores records of emergency vehicles as well as traffic signals together with prediction results within its database.

The database collection maintains a schema composed of vehicle_id, license_plate, timestamp, location, signal_status, priority_level.

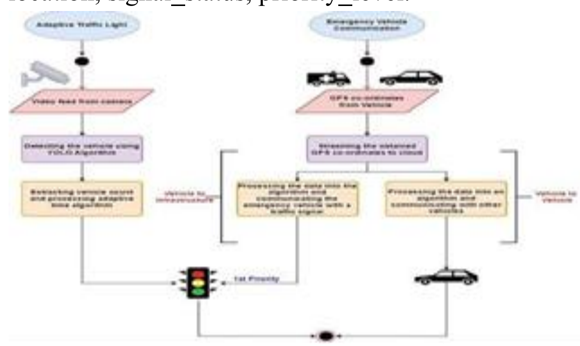

Figure.1 Architecture Diagram

d) Data Processing:

Technologies: OpenCV, TensorFlow, or PyTorch.

Real-time visual sensing detects emergency vehicles as part of its function through this system.

The platform employs workflow operations to take traffic video input then performs data processing that applies emergency vehicle detection algorithms YOLO or Faster R-CNN to recognize these vehicles.

Structure: Police departments utilize Traffic Data systems for storage of real-time video metadata as well as vehicular data detection details.

System Logs: Keeps records of signal changes and user actions for audit purposes.

e) System Workflow:

1. The cameras used by the system continuously monitor traffic activities. The system Real-time activation of emergency vehicle detection happens through frame processing performed by the system.
2. The system detects emergency vehicles after which it automatically prioritizes traffic signals to advance vehicles on the approved route.
3. Dynamic Routing operates through algorithms managed by AI to reroute other vehicles in order to prevent congestion.
4. The system presents visibility of analytical data and logs through front-end interfaces for assessing how the system performs.
5. The system maintains data integrity by using a

backend structure that contains security elements which ensure proper and unadulterated records.

VIII. RESULTS

YOLOv5 proved effective at distinguishing emergency and non-emergency vehicles in detection tasks. Emergency vehicles detection yielded 0.90 accuracy while the model achieved 0.73 accuracy for detecting non-emergency vehicles. This system operated efficiently in real-time to support timely decisions and identification needs that intelligent traffic systems require.

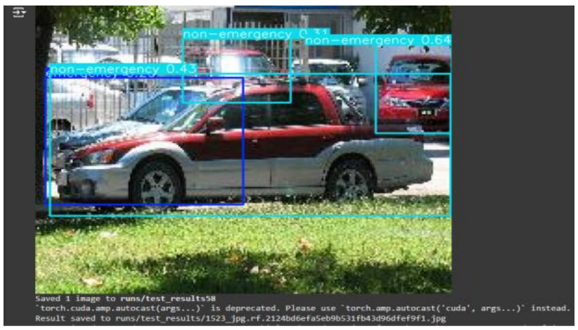

Figure.2. Emergency Vehicle Detected With Accuracy of 0.90

IX. CONCLUSION

The proposed visual sensing-based traffic management system resolves urban traffic problems using emergency vehicle operational prioritization mechanisms that function in real time. The real-time video analysis through AI-based detectors recognizes emergency vehicles for giving them priority status to speed up response times alongside lowering delays. Correct detection along with classification of emergency vehicles emerges from employing YOLO and Faster R-CNN object detection technology with CNN classification systems. Reliability in video monitoring enhances with video preprocessing methods that apply noise reduction alongside background subtraction. The system performs real-time operations to enable adaptive signal control protocols and traffic routing protocols for optimizing security operations. When deployed with present road systems the flexible AI technology improves emergency response efficiency for the development of secure intelligent streets.

The developed visual sensing system demonstrates its capacity to function as an efficiently adaptive and data-driven emergency vehicle prioritization system for urban traffic management.

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