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A Smart Emergency Response Framework using AI and IoT for Real-Time Traffic Congestion Detection and Ambulance Routing

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ABSTRACT

This paper presents a Smart Traffic Management Alert System (STMAS) designed to improve emergency medical response time in urban environments by leveraging Internet of Things (IOT) technology. The system addresses the critical delays ambulances face due to conventional, fixed-time traffic signal patterns that fail to adapt to real-time emergency needs. Our approach integrates GPS- enabled ambulance tracking, microcontroller-based traffic signal control, cloud-based data processing, and digital display boards to ensure prioritized passage for emergency vehicles. When an ambulance is detected within a predefined radius of an intersection, the system first activates LED display boards with warning messages to alert nearby drivers and pedestrians. Once the path is cleared, the corresponding traffic signal is switched to green in the ambulance's direction. Tests and simulations show that the system can greatly reduce the time ambulances spend in traffic and improve coordination between emergency services and traffic control. This determining the patient's chances of survival. Unfortunately, traditional traffic control systems, which are based on fixed-time signal patterns, lack the flexibility to adapt to real-time traffic conditions or prioritize specific vehicles. As a result, ambulances often face unnecessary delays while navigating through crowded intersections, even when their journey is time-critical. These delays can be the difference between life and death, highlighting the urgent need for an intelligent, responsive traffic management system.

1. INTRODUCTION

Traffic congestion has become a growing challenge in most urban areas due to the continuous rise in population, vehicle ownership, and limited road infrastructure. This problem not only affects daily commuters but also has a serious impact on emergency services. In cases such as heart attacks, severe accidents, strokes, or other medical emergencies, every second plays a crucial role in determining the patient's chances of survival. Unfortunately, traditional traffic control systems, which are based on fixed-time signal patterns, lack the flexibility to adapt to real-time traffic conditions or prioritize specific vehicles. As a

result, ambulances often face unnecessary delays while navigating through crowded intersections, even when their journey is time-critical. These delays can be the difference between life and death, highlighting the urgent need for an intelligent, responsive traffic management system. The advancement of the Internet of Things (IoT), cloud computing, and real-time data analytics has opened up new opportunities to address these challenges. IoT makes it possible for devices and systems to share data instantly, allowing traffic lights, sensors, and emergency vehicles to communicate effectively.

2. LITERATURE REVIEW

Mahalakshmi et al. proposed an Adaptive Ambulance Monitoring System Using IoT, using low-cost IoT components and signal override techniques to improve emergency response. However, RFID-based vehicle instrumentation and coarse localization may limit scalability. Chowdhury et al. developed an IoT-Based Emergency Vehicle Services system integrating UAVs and ground IoT for end-to-end emergency support. Its limitations include UAV regulations, limited flight duration, and weather sensitivity. Kheder et al. presented a Real-Time Traffic Monitoring System Using IoT-Aided Robotics, offering improved coverage, redundancy, and practical evaluation. Nevertheless, robotics increases cost, complexity, and deployment challenges. Mehendale proposed an AI-Based Emergency Vehicle Priority System using audio-based siren detection, achieving high detection accuracy with low bandwidth requirements. Its performance may decrease in noisy urban environments and depends on siren availability. Bakir presented SPAR-4-SLR, a systematic review of AI-based traffic research, providing a broad overview of current developments and helping position new studies. However, as a survey, it contributes no new experimental results for practical emergency traffic management.

3. PROBLEM STATMENT

Rapid urbanization and the exponential growth of vehicles have led to severe traffic congestion in metropolitan and developing cities, creating a major challenge for emergency medical services. Ambulances, which require immediate and uninterrupted passage, are often delayed due to unplanned congestion, lack of real-time traffic visibility, poor coordination between traffic control systems, and absence of intelligent routing mechanisms. Existing traffic management systems are largely static, relying on pre-timed signals and limited monitoring, and they do not provide priority access to emergency vehicles. Even when GPS-based navigation is used, it typically reacts to current traffic rather than predicting congestion or dynamically clearing routes. Additionally, there is minimal integration between roadside infrastructure, traffic signals, and emergency services, resulting in inefficient communication and delayed response times. These delays can critically impact patient survival rates, especially in life-threatening situations such as accidents, cardiac arrests, or medical emergencies where every second is crucial.

Furthermore, current solutions lack the capability to process large-scale real-time data from multiple sources such as cameras, sensors, and connected vehicles. Without advanced analytics, it becomes difficult to detect congestion patterns, predict traffic build-up, and make proactive decisions. There is also a lack of automated alerting systems that can inform ambulances about the best possible routes or notify traffic authorities to clear the path. To address these limitations, there is a pressing need for an integrated, intelligent system that leverages Internet of Things (IoT) devices for continuous traffic data collection and Artificial Intelligence (AI) techniques for real-time congestion detection, prediction, and decision-making. Such a system should be capable of analysing live traffic feeds, identifying congestion hotspots, predicting future traffic conditions, and providing optimized routing along with alert mechanisms for ambulances. By doing so, it aims to minimize delays, enhance coordination between traffic infrastructure and emergency services, and ultimately improve the efficiency and reliability of emergency response systems, contributing to better public safety and smart city development.

4. OBJECTIVE

The primary objective of this research is to design and develop an intelligent system for real-time traffic congestion detection and efficient ambulance alerting by integrating Internet of Things (IoT) and Artificial Intelligence (AI) technologies. The system aims to continuously collect traffic data from multiple sources such as cameras, sensors, and GPS-enabled devices using IoT infrastructure, and process this data using AI algorithms to accurately detect and predict congestion levels. Another key objective is to provide dynamic and optimized route guidance to ambulances, ensuring the fastest possible path to their destination while avoiding congested areas. The research also focuses on developing an automated alert mechanism that can notify ambulances, traffic control systems, and nearby vehicles in real time to facilitate smoother movement of emergency vehicles. Additionally, the system seeks to improve coordination between traffic management authorities and emergency services by enabling intelligent decision-making

and communication. By achieving these objectives, the proposed solution aims to significantly reduce ambulance response time, enhance road safety, and contribute to the development of efficient smart city transportation systems.

5. METHODOLOGY

The system will identify traffic congestion in real-time and give an intelligent route-clearing mechanism to ambulances through the use of Artificial Intelligence (AI) and Internet of Things (IoT) technologies. The system will see to it that ambulances arrive at hospitals promptly by auto-controlling traffic signals and informing surrounding vehicles and authorities.

A. System Architecture Overview

The system has four principal elements:

1. IoT Sensors and Devices: Mounted on vehicles and roads to gather real-time data including traffic density, vehicle count, and speed.

2. AI-Based Processing Unit: Relies on image processing and machine learning software to process data from cameras and sensors.

3. Communication Module: Facilitates data exchange between traffic control center, IoT nodes, and ambulance through technologies like GPS, GSM, or Wi-Fi.

4. Cloud Server / Control System: Holds information, processes it, and makes real-time decisions like adjusting traffic lights or notifying surrounding vehicles.

B. Data Collection

1. Traffic cameras and ultrasonic sensors are installed at key intersections to keep tabs on vehicle density and traffic flow.
2. GPS and RFID modules are fitted in ambulances to monitor their live location and movement.
3. The acquired data (number of vehicles, speed, and level of congestion) is transmitted to the central control system using IoT gateways.

C. AI-Based Data Processing

1. The AI platform employs Computer Vision (CV) and Machine Learning (ML) algorithms to process real-time video streams from cameras.
2. Image processing algorithms (such as YOLO or OpenCV-based detection of vehicles) detect and determine the number of vehicles at intersections.
3. A Traffic Density Algorithm is used to categorize roads as:
   - Low congestion
   - Moderate congestion
   - High congestion
4. On the basis of this, the system forecasts potential congestion and recommends alternate routes.

D. Ambulance Detection and Identification

1. Every ambulance has a GPS module and an RFID tag or IoT device with a unique identifier.
2. In emergency mode (on duty), the ambulance transmits its location, speed, and route information to the control system.
3. The control system detects the ambulance and its real-time movement using AI and IoT integration.

E. Intelligent Traffic Signal Control

1. In the event that an ambulance is heading to a traffic signal, the system:
2. Locates the position and direction of the ambulance through GPS.
3. Issues an override command to the traffic light controller.
4. Switches the ambulance route signal to GREEN and other routes to RED to create a direct path for the ambulance.
5. Once the ambulance has crossed the junction, the signal timing resumes normal operation automatically.

F. Communication and Alert System

1. Inward-bound vehicles are given a real-time notification via a mobile application or electronic display boards with the message:
1. "Ambulance Approaching – Clear the Lane."
2. The Traffic Control Room is also informed of the ambulance route and congestion level for coordination purposes.

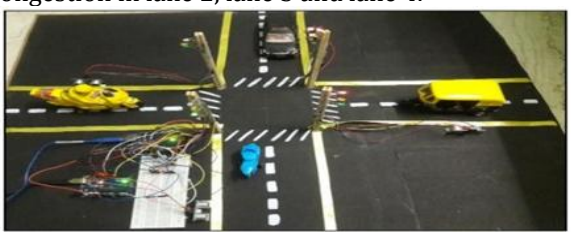
6. CLASSIFICATION

The proposed research on Traffic Congestion Detection and Alerting Ambulance using IoT and AI can be classified as an interdisciplinary study that lies at the intersection of intelligent transportation systems, Internet of Things (IoT), and artificial intelligence. It primarily falls under the domain of smart city applications, where advanced technologies are used to improve urban infrastructure and public safety. From a technical perspective, the work is categorized under real-time embedded systems and distributed sensor networks, as it involves the deployment of IoT devices such as traffic cameras, GPS modules, and road sensors for continuous data collection. The research also belongs to the field of computer vision and machine learning, as AI models (e.g., deep learning algorithms) are used to detect vehicles, analyse traffic density, and predict congestion patterns. Furthermore, it can be classified under cyber-physical systems since it integrates physical components (roads, vehicles, sensors) with computational intelligence and communication networks to enable automated decision-making. In terms of application, the study is part of emergency response and healthcare support systems, focusing on improving

ambulance mobility and reducing response time during critical situations. Overall, this research is a combination of IoT-based data acquisition, AI-driven analytics, and intelligent traffic management, contributing to next-generation smart transportation and public safety solutions.

7. RESULT AND DICUSSION

The android app is developed to show the traffic congestion in 2km radius of the ambulance. Map is displayed in the app which makes the user (ambulance driver) to have a better view of the traffic congestion. To demonstrate the working, a real time traffic junction is considered which Jayanagar 3rd block is, Bangalore, India. In Fig. 4, lane 1 is south direction, lane 2 is east direction, lane 3 is north direction and lane 4 is west direction. It can be observed that lane 1 signal is green which means that the vehicles are moving from lane 1 there is traffic congestion. Lane 2, lane 3 and lane 4 signals are red also the vehicles are up to 200m which means that there is traffic congestion in lane 2, lane 3 and lane 4.



CONCLUSION

One of the major issues with the public transportation system in recent times is traffic congestion. The traffic congestion often blocks the path of the emergency vehicles which may prove fatal at times. Also, the number of deaths due to delay in the arrival of emergency vehicles have increased to a greater extent in recent times. Emergency vehicle Ambulance needs to be on time to prevent loss of human life. Thus, helping an emergency vehicle to move out of traffic congestion is very much essential in the current traffic scenario. Traffic Congestion Detection and Alerting Ambulance system are developed to overcome the above problem. In this system, the traffic congestion detected in the traffic signal. If there is traffic congestion up to 200m or above in a particular lane, is detected and an ambulance is alerted before 2km from the traffic signal so that the ambulance driver takes alternative route to reach the hospital. This approach minimizes human intervention, facilitating large-scale implementation in busy urban areas. Through the use of microcontrollers and internet-based APIs, quick and reliable data transfer is achieved between moving ambulances and fixed traffic devices. Integrating this solution into city traffic networks enhances the ability of emergency services to respond promptly, potentially saving lives and decreasing accident risks related to delayed medical attention. This project demonstrates how IoT and location-based technologies can transform traditional traffic systems into intelligent, responsive networks suitable for future smart city paradigms.

Future improvement directions for this system include:

1) Expanded Coverage: Deployment of additional IoT-enabled traffic lights across both urban centres and rural highways to maximize system reach and effectiveness.

2)Advanced Communication Infrastructure: Adoption of robust communication channels such as 4G/5G networks or satellite connectivity to ensure real-time data transfer even in regions with unreliable Wi-Fi access.

3) Hospital System Integration: Direct integration with hospital emergency systems so that medical staff are fully prepared prior to patient arrival, further streamlining emergency response processes.

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