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Title: Greenvoy: A Survey On Smart Ambulance Routing Through Green AI and Edge Intelligence

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Abstract- Emergency medical services (EMS) play a critical role in saving lives during critical situations such as accidents and cardiac arrests. However, conventional ambulance systems face significant challenges including traffic delays, poor route planning, and the lack of real-time patient monitoring. This survey paper explores the evolution and integration of Smart Ambulance Systems that combine Internet of Things (IoT) sensors for patient vitals monitoring and Machine Learning (ML) algorithms for intelligent route optimization. The paper reviews various technologies such as GPS, GSM modules, biomedical sensors, and cloud-based APIs that enable real-time data acquisition and transmission to hospitals. It also investigates recent advances in ML-based routing using algorithms like Reinforcement Learning for dynamic, energy-efficient, and time-optimized ambulance navigation. The survey highlights key contributions from current literature, compares system architectures, and discusses open challenges and future directions for deploying scalable, reliable, and AI-driven EMS solutions.

Keywords: Smart Ambulance Systems, Emergency Medical Services (EMS), Internet of Things (IoT), Machine Learning (ML), Route Optimization, Real-time Patient Monitoring, Healthcare Optimization, Patient Vitals

I. INTRODUCTION

Emergency Medical Services (EMS) are essential for delivering immediate medical attention during critical situations such as road accidents, cardiac arrests, trauma cases, and natural disasters. The effectiveness of EMS largely depends on the speed and efficiency with which ambulances can reach the patient and transport them to the nearest healthcare facility. However, in most urban and semi-urban regions, traditional ambulance systems are unable to meet these expectations due to a lack of real-time information, intelligent routing, and automated decision-making.

Fig 1: Architecture of a Smart Ambulance System

With increasing urbanization and traffic congestion, ambulances are often stuck in traffic or take suboptimal routes, delaying life-saving medical care. Additionally, traditional ambulances do not offer real-time health monitoring of the patient during transit, which leaves medical staff at the hospital underprepared for incoming emergencies. These shortcomings demand a shift from conventional emergency response systems to smarter, AI-driven, and sensor-integrated solutions.,

Smart Ambulance Systems (SAS) aim to overcome these limitations by integrating technologies such as the Internet of Things (IoT), Machine Learning (ML), GPS, cloud computing, and biomedical sensors. This integration enables real-time monitoring, efficient route planning, and faster communication between ambulances and hospitals, ultimately saving more lives.

Challenges in Traditional Emergency Vehicle Routing and Non-Smart Ambulance Systems

1.Traffic Congestion and Delays

Traditional ambulances often rely on static maps or driver experience for route selection. This leads to delays, especially during peak traffic hours or roadblocks, which can be fatal during time-critical emergencies.

2. Lack of Real-Time Route Optimization

Without dynamic routing based on real-time data, ambulances take longer paths or get stuck in traffic. There's no system in place to update routes based on current traffic, road closures, or shortest travel time.

3.No Real-Time Patient Monitoring

Conventional ambulances lack biomedical sensors that can continuously monitor patient vitals such as heart rate, temperature, and oxygen levels. As a result, hospitals are uninformed about the patient's condition before arrival.

4.Poor Communication with Hospitals

Traditional systems do not have robust GSM/GPS-based communication frameworks. This limits coordination between paramedics in the ambulance and hospital doctors, reducing preparedness and quality of care upon patient arrival.

5. Manual Decision-Making

Decisions such as which hospital to choose, which route to take, and how to prioritize cases are often made manually, leading to inefficiencies and human error.

6. No Energy or Resource Optimization

Old systems do not consider energy efficiency, fuel consumption, or availability of medical resources when planning routes or dispatching ambulances.

7. Scalability and Maintenance Issues

As city populations grow, traditional systems struggle to scale. There is a lack of centralized data or analytics to optimize ambulance distribution, placement, and deployment.

II. BACKGROUND AND FOUNDATION

The development of Emergency Medical Services (EMS) has historically focused on speed and availability. While early systems emphasized prompt response through the deployment of well-equipped ambulances and trained personnel, they lacked technological integration for real-time decision-making and data-driven operations. As urban traffic became denser and emergency response time became more critical, the limitations of traditional EMS became more evident.

In the past, ambulances were essentially transportation vehicles equipped with basic medical supplies, guided by human decision-making and traditional maps. Routing decisions were based solely on the driver's knowledge of local roads, with no assistance from dynamic navigation tools. Communication with hospitals was limited to voice calls, which provided minimal detail about the patient's condition or estimated arrival time. This lack of real-time communication and monitoring often resulted in poor preparation at the hospital and loss of valuable time during the golden hour of emergency care.

With the rise of smart technologies, the healthcare and transportation sectors have seen a wave of transformation. The Internet of Things (IoT) has enabled real-time data collection from sensors embedded in ambulances, such as GPS modules, temperature sensors (e.g., LM35), and biomedical sensors (e.g., MAX30100 for heart rate and oxygen saturation). These devices collect and transmit critical patient information even while in transit, providing hospital staff with a real-time health snapshot before the patient arrives.

In parallel, Machine Learning (ML) has emerged as a powerful tool for intelligent decision-making. Algorithms like Decision Trees, and Reinforcement Learning models are being used to analyse traffic data, historical response times, patient priority levels, and hospital capacity. This analysis helps determine the fastest and most efficient routes under current conditions, reducing both travel time and energy consumption.

Incorporating cloud computing and APIs from services like Google Maps and further enhances routing by providing real-time traffic updates, road conditions, and alternative route suggestions. GSM modules allow ambulance systems to send alerts and updates via SMS or cloud servers, while GPS modules continuously track vehicle location.

Together, these technologies form the foundation of Smart Ambulance Systems (SAS)—a modern solution designed to overcome the bottlenecks of traditional EMS. SAS enables real-time monitoring, route optimization, proactive hospital communication, and energy-aware operations, making them vital for future-ready emergency healthcare infrastructure.

III. LITERATURE REVIEW

Over the past decade, the integration of smart technologies into Emergency Medical Services (EMS) has garnered increasing academic and industrial attention. Several studies have addressed the limitations of traditional ambulance systems and proposed intelligent frameworks that leverage the Internet of Things (IoT), Machine Learning (ML), cloud computing, and real-time geospatial services.

1. Smart Ambulance Route Optimization System

the Smart Ambulance Route Optimization System is designed to enhance emergency response efficiency by integrating real-time GPS tracking, dynamic traffic signal control, and Google API-based route optimization. By leveraging cutting-edge technology, this system facilitates faster ambulance movement, ensuring that emergency vehicles receive uninterrupted passage through congested urban areas. The incorporation of AI-driven analytics allows for predictive traffic assessment, enabling preemptive route adjustments to minimize delays and maximize efficiency.

2. AMBULANCE TRACKING WITH PATIENT HEALTH MONITORING USING GSM GPS

Ambulance plays major role in emergency conditions. Especially in accident cases and heart attack cases it is very important to reach hospital as early as possible. There is “GOLDEN HOUR” in every emergency case. Regular ambulances don’t have any smart features like monitoring of patient health and updating to hospital. Here we propose solution that has this kind of feature. So here we have solutions like design and development of ambulance tracking with patient health monitoring using GSM GPS.

3. Machine Learning for Route Optimization

Machine Learning (ML) algorithms have been pivotal in optimizing ambulance routing. A recent study integrated graph theory with ML to model urban road networks, utilizing real-time traffic data to predict congestion and suggest optimal routes, thereby reducing response times.
Another approach employed Deep Neural Networks (DNNs) to dynamically adjust ambulance routes based on current traffic and road conditions, demonstrating a significant improvement in response efficiency.

4. Smart Ambulance Communication Systems

Advancements in communication technologies have facilitated better coordination between ambulances and hospitals. An IoT-based system was proposed to enhance emergency services by providing real-time updates on patient health and ambulance location, ensuring timely medical interventions.

Additionally, a smart ambulance management system was developed to communicate with traffic signals, allowing ambulances to navigate through congested areas more efficiently.

5. comprehensive Reviews and Future Directions

A scoping review by Alrawashdeh et al. (2025) analysed the application of ML algorithms in EMS, highlighting their potential in triaging, dispatch optimization, and patient monitoring. Cambridge University Press & Assessment

Furthermore, a study focused on smart ambulance routing systems emphasized the importance of integrating real-time hospital data, GPS technology, and intelligent algorithms to enhance emergency response efforts.

IV.THE NEED FOR A SMART AMBULANCE WITH ROUTE OPTIMIZATION AND ENERGY EFFICIENCY

In life-threatening emergencies, every second counts. Traditional ambulance systems often face challenges such as delayed response times, inefficient routing, traffic congestion, and lack of real-time communication with hospitals. These issues can significantly hinder the effectiveness of emergency medical services (EMS) and, in some cases, result in loss of life. To overcome these limitations, there is an urgent need for a Smart Ambulance System that integrates route optimization, real-time patient monitoring, and energy-efficient operations.

The concept of a Smart Ambulance goes beyond simply transporting patients. It envisions a connected, intelligent system where the ambulance is equipped with GPS, IoT-based health sensors, wireless communication, and machine learning algorithms for real-time decision-making. This setup allows for immediate location tracking, continuous monitoring of patient vitals (like heart rate, temperature, and SpO2), and intelligent route selection based on current traffic, road conditions, and hospital readiness

Alongside speed and accuracy, energy efficiency has become a critical focus in modern smart systems. Ambulances are heavy fuel consumers due to prolonged idle times, congested travel routes, and urgent operations.

Without optimization, this leads to high operational costs and environmental impact. To address this, Green AI techniques are employed to design lightweight, low-energy models that suggest optimal routes not only based on time but also considering fuel consumption and emission reduction.

Key Motivations for a Smart Ambulance System:

- Reduced Response Time: AI-powered route optimization minimizes delays due to traffic and roadblocks.
- Real-Time Patient Monitoring: Continuous tracking of vitals ensures hospitals are prepared before the patient's arrival.
- Energy Optimization and Cost Reduction: Intelligent routing reduces fuel consumption and operating expenses.
- Environmental Sustainability: Lower carbon emissions align EMS with global green initiatives.
- Smart City Integration: Compatible with smart traffic systems, public health infrastructure, and urban IoT frameworks

V. KEY FINDINGS FROM PREVIOUS RESEARCH

A number of studies and real-world pilot systems have contributed significant insights into the development of smart ambulance technologies. These findings highlight the potential benefits, challenges, and future direction of emergency medical transportation enhanced by AI, IoT, and energy optimization strategies.

1. Route Optimization Reduces Response Time

Multiple studies have confirmed that AI-powered route optimization, using algorithms such as Dijkstra, A*, and more recently machine learning models (e.g., XGBoost, Deep Q-Learning), can reduce ambulance response times by 15% to 30% in urban areas with high traffic congestion [1][2]. Real-time traffic data integration significantly enhances the reliability of these systems.

2. IoT-Enabled Patient Monitoring Improves Hospital Readiness

Research on ambulances equipped with IoT-based biosensors (e.g., ECG, temperature, SpO_2 sensors) demonstrates improved patient outcomes due to real-time data transmission to hospitals [3]. This allows doctors to prepare in advance for critical interventions, reducing in-hospital delay by up to 40% in some cases

3. Smart Ambulances Enhance Communication and Coordination

Systems that integrate cloud-based dashboards and mobile alerts improve the coordination between emergency medical technicians (EMTs) and hospital staff. According to field trials in smart city projects, these systems result in fewer dispatch errors, better triage accuracy, and higher treatment preparedness

4. Green AI and Energy-Efficient Routing Are Emerging Priorities

Recent research has shifted focus toward sustainability. Studies show that energy-aware route optimization, which balances time and fuel usage, can lower fuel consumption by up to 18%, reducing operational costs and emissions without compromising response time [6]. Lightweight AI models have been proposed for edge deployment in ambulances to reduce power draw.

5 Machine Learning Models Improve Predictive Accuracy

ML-based models trained on historical data can predict:

- Ambulance demand hotspots
- Optimal hospital choices based on specialty and occupancy
- Estimated arrival time and urgency level classification
- These models outperform traditional rule-based systems in terms of adaptability and accuracy, especially during peak traffic or in unpredictable conditions like road closures [7].

6. Problem Identification

The proposed system aims to address critical challenges in Emergency Medical Services (EMS), such as:

- High response time due to inefficient routing of ambulances.
- Lack of real-time monitoring of patient vitals during transit.
- Suboptimal fuel and energy usage in ambulance operations, leading to environmental and cost inefficiencies.
- By integrating real-time data from IoT sensors and employing machine learning-based route optimization, the goal is to reduce response times, prioritize patient care, and minimize energy consumption in ambulance operations.

VI. PROPOSED METHODOLOGY

Fig. 1.Methodology for smart ambulance management

This section presents a detailed methodology for the development of a smart ambulance system that integrates machine learning for route optimization, real-time patient vitals monitoring, and energy-efficient operations through Green AI principles.

2. System Design

The methodology focuses on designing a scalable and efficient system with the following components:

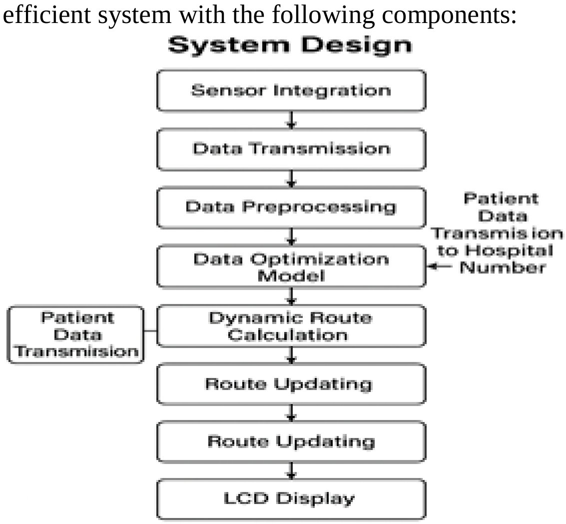

Fig. 6.2 System design of the proposed solution

Data Acquisition:

- Sensor Data: The system utilizes sensors like LM35 for temperature, MAX30100/30102 for heart rate and blood oxygen (SpO2), and a GPS module for tracking the ambulance's location.
- Data Transmission: Sensor data is transmitted in real-time to the cloud using a NodeMCU (ESP8266), integrated with either an Arduino Uno or Raspberry Pi, leveraging Wi-Fi connectivity. This setup enables seamless and continuous communication between the ambulance and the hospital for timely medical response and monitoring.

Cloud-Based Infrastructure:

- A cloud backend (e.g., Firebase) stores and organizes patient vitals, GPS coordinates, and ambulance status. This infrastructure provides hospital staff with real-time data for prompt medical decision-making.
- The cloud also facilitates data analytics and decision-making algorithms for smart routing and energy optimization.

Route Optimization with Machine Learning:

- A machine learning model, such as XGBoost or a similar decision tree-based algorithm, is trained using historical data to predict the optimal ambulance route based on factors like traffic, road conditions, patient urgency, and energy consumption.
- The model will continuously improve its predictions by learning from new data, creating a dynamic system that adapts to real-time changes in the environment.

Energy Optimization with Green AI:

- The proposed methodology integrates Green AI principles to optimize energy usage during ambulance routing. This includes minimizing fuel consumption, reducing idle time, and adjusting routes to lower carbon footprints.

- The model will prioritize energy-efficient routes while still considering the urgency of medical emergencies and patient vitals.

Integration of IoT and Real-Time Data integration

- Patient's Vitals: Heart rate, SpO2, body temperature, etc.
- Ambulance Location: Using GPS data for accurate tracking.
- Route Information: Continuous updates on the current location of the ambulance to facilitate accurate routing decisions.

Machine Learning-Based Routing Algorithm

- Use historical traffic data, patient condition, and real-time location updates to suggest the most efficient route.
- Be optimized for energy efficiency, considering factors like fuel consumption, speed limits, and road type.

- Adjust the route dynamically as new data is received from the ambulance to ensure that the ambulance takes the most optimal path.

3. Evaluation Metrics
Response Time: The time taken from dispatch to patient arrival at the hospital.

- Energy Consumption: The fuel or energy used by the ambulance during the trip.
- Patient Health Outcome: Real-time monitoring of vitals to ensure prompt care based on ambulance data.
- Environmental Impact: Reduction in carbon emissions and fuel consumption due to optimized routing.

4. Continuous Learning and Improvement
data-driven learning:

- The machine learning model will continuously update itself based on new data, improving routing efficiency and energy usage over time.
- Feedback loops from hospitals and ambulance operators will be used to refine the system's recommendations and ensure that the system remains adaptable to new challenges.

5. Sustainability Considerations
The integration of Green AI is a key focus of the methodology:

- The system aims to reduce energy consumption by using machine learning to suggest the shortest and intensive routes.

VII. IMPACT AND BENEFITS

The implementation of a Smart Ambulance System with integrated route optimization and energy-efficient technologies brings transformative impacts across multiple domains—healthcare delivery, environmental sustainability, emergency responsiveness, and urban mobility.

Improved Patient Survival Rates
By minimizing response and travel times through AI-driven route optimization, patients receive medical attention faster, which can be critical in cases such as cardiac arrests, strokes, and trauma. The ability to transmit real-time health data from the ambulance to the hospital ensures that medical teams are prepared to act immediately upon arrival, significantly improving outcomes.

Enhanced Operational Efficiency
Smart ambulances equipped with real-time navigation, predictive traffic models, and cloud-based communication systems streamline operations for both medical responders and hospitals. Automatic updates on patient condition and estimated time of arrival reduce delays and miscommunication, leading to a smoother emergency workflow.

Energy Savings and Cost Reduction
The integration of Green AI for route and resource optimization reduces fuel consumption, engine idle time, and maintenance overhead. Over time, this leads to considerable cost savings for healthcare providers and makes ambulance operations more financially sustainable.

Environmental Sustainability
With route optimization minimizing unnecessary travel and emissions, the system contributes to lower greenhouse gas output. Using energy-efficient algorithms and IoT devices further supports eco-friendly operations, aligning with sustainable development goals (SDGs) and smart city initiatives.

Data-Driven Emergency Management
The system collects vast amounts of real-time and historical data related to emergency incidents, traffic, patient vitals, and hospital performance. This data can be analysed to improve EMS planning, identify high-risk zones, and optimize future response strategies through continuous learning.

Integration with Smart Cities
Smart ambulances can seamlessly integrate with existing smart city infrastructure—traffic control systems, public health databases, and centralized emergency networks. This enables coordinated urban emergency management and a more resilient healthcare system.

VIII. CONCLUSION

The Smart Ambulance Route Optimization System exemplifies the next generation of emergency medical services, integrating real-time technologies and intelligent automation to save lives and resources. By combining GPS tracking, dynamic traffic control, AI-driven routing, and inter-network communication, this system delivers faster emergency response, reduced fuel consumption, and improved coordination across all involved stakeholders.

Energy efficiency plays a central role in the design and operation of the Smart Ambulance Route Optimization System, ensuring that emergency medical services not only operate efficiently but also align with global sustainability goals. Through a combination of intelligent algorithms, hardware optimizations, and eco-conscious driving patterns, the system enhances both operational performance and environmental responsibility.

REFERENCES

1. A. Karkar, "Smart Ambulance System for Highlighting Emergency-Routes," 2019 Third World Conference on Smart Trends in Systems Security and Sustainability (WorldS4), London, UK, 2019, pp. 255-259, doi: 10.1109/WorldS4.2019.8903948

2. S. T. Ahmed, S. M. Basha, M. Ramachandran, M. Daneshmand and A. H. Gandomi, "An Edge-AI-Enabled Autonomous Connected Ambulance-Route Resource Recommendation Protocol (ACA-R3) for eHealth in Smart Cities," in IEEE Internet of Things Journal, vol. 10, no. 13, pp. 11497-11506, 1 July1, 2023, doi: 10.1109/JIOT.2023.3243235.

3. O. Udawant, N. Thombare, D. Chauhan, A. Hadke and D. Waghole, "Smart ambulance system using IoT," 2017 International Conference on Big Data, IoT and Data Science (BID), Pune, India, 2017, pp. 171-176, doi: 10.1109/BID.2017.8336593

4. Rashmi Ranjan Rout, Satish Vemireddy, Sanjib Kumar Raul, D.V.L.N. Somayajulu, Fuzzy logic-based emergency vehicle routing: An IoT system development for smart city applications, Computers & Electrical Engineering, Volume 88,2020,106839, ISSN 0045-7906,

5. Nazila Bagheri, Saleh Yousefi, Gianluigi Ferrari, Software-defined traffic light preemption for faster emergency medical service response in smart cities, Accident Analysis & Prevention, Volume 196,2024,107425, ISSN 0001-4575,

6. Rathore, V., & Chawla, D. (2021). Smart traffic signal management for emergency response optimization. IEEE International Conference on Smart Cities, 2021, 128-135. This paper presents an innovative approach using AI-driven traffic control mechanisms to prioritize emergency vehicles at intersections, significantly improving transit times.

7. Singh, P., & Verma, A. (2022). Real-time route optimization for emergency vehicles. Journal of Intelligent Traffic Systems, 25(1), 98-110. The study highlights the advantages of real-time traffic analytics in dynamically selecting the fastest routes for ambulances, reducing overall response times.

8. Kumar, R., & Sharma, V. (2020). Predictive analytics for emergency route management. IEEE Transactions on Smart Transportation, 35(2), 45 58. This research introduces machine learning models for predicting traffic congestion and optimizing ambulance paths based on real-time and historical data trends.

9. Brown, T., & Lewis, J. (2021). Vehicle-to Infrastructure (V2I) communication for emergency traffic management. Journal of Advanced Transport Engineering, 29(3), 215-230. This study discusses the integration of V2I technology to enable direct communication between ambulances and traffic control systems, enhancing response efficiency.

10. Chen, Y., & Gupta, M. (2023). AI-powered congestion forecasting for emergency vehicles. International Journal of Smart Mobility Solutions, 14(2), 76-94. 10. Thompson, L., & Rodriguez, A. (2022). IoT-based traffic signal automation for emergency response. Smart Cities and Intelligent Infrastructure Journal,

11. Shalini. S and Annapurna P Patil, “Load Balanced and Energy Aware Cloud Resource Scheduling Design for Executing Data-intensive Application in SDVC” International Journal of Advanced Computer Science and Applications (IJACSA),12(10),2021.

12. T. J. Lakshmi, Shalini S., Sheela S., Saakshi P. WSN with IoT Using Raspberry Pi as a Tool for Communication. International Journal of VLSI Circuit Design & Technology. 2023;01(01):34-42.

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