SmartClear: AI-Enhanced Traffic Management for Emergency Services

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***Abstract*—This paper introduces an AI-boosted traffic management system, called SmartClear that has been designed specifically to cut down on response time for emergencies by optimizing traffic signals. Conventional traffic control efforts do not always cater for the immediate needs of emergency vehicles and as result they experience avoidable delays. These are capable of adapting to real time traffic conditions using data like GPS and sensor data alongside complex CNN attention models and LSTM video captioning based on modern artificial intelligence. This is done through real-time adjustment of signal timings depending on the prevailing traffic patterns at a given intersection, which may be set in advance or changed instantaneously even without the pre-cabled infrastructure for different transport modes. The four layered system architecture embraces data acquisition, processing, decision making and actuation that facilitate efficient flows and prioritization in terms of emergency responses. Nevertheless, there are some limitations highlighted in this study: precise real-time information and reliable infrastructure requirements; multimodal mobility with blockchain security being among future improvements.**

Keywords: Artificial Intelligence, Traffic management, Convolutional Neural Network(CNN).

1. INTRODUCTION

Timely arrival of emergency services is crucial to patients' survival in metropolitan areas such as India where traffic jams are a major impediment. In order to counter this problem SmartClear, an AI-based transportation management system for emergency response vehicles, has been developed to minimize transit delays. The existing smart traffic systems are computer vision based, sensor networks based, big data analytics based and that uses artificial intelligence (AI) to adjust signal timings with focus on mitigating congestion. Nevertheless, they concentrate mostly on typical road users, thereby ignoring the particular needs of the emergency service providers.

SmartClear project aims at addressing this gap through coming up with automated traffic signal preemption system suitable for emergency vehicles only. SmartClear helps in pro- viding real-time support to on-site traffic management by using big data analytics together with AI. At the moment, current traffic management is urban-handled signals that change timing based on sensor data. Nevertheless, these "traffic responsive" systems are not good at adapting to real-time demand. However, when connected and autonomous vehicles (CAVs) emerged, it brought possibilities for improvement since there can be proactive communication between the traffic system and the vehicle. Still, this is expected to take some time before a large number of people adopt CAV technology. Hence, in the meantime, local areas will need to manage their CAV systems in quite similar ways as existent "traffic responsive" systems. Emergency services face a unique challenge in that, while general traffic management is well-studied, the dynamic nature of traffic conditions constantly changes. Emergency service requirements are not considered by existing systems, which depend on predetermined ways of removing obstacles from the roads and thus could block emergency routes. In addition, these systems struggle to adjust to real-time changes because it takes long to re-optimize them. To address this challenge, SmartClear has devised effective methods of managing traf- fic that specifically suit emergency services, prioritizes road clearance planning and utilizes current traffic details.

A. Objectives

The aim of the SmartClear system is to get an accurate view of the present state of affairs with respect to traffic through real-time monitoring using cameras and sensors. Using artificial intelligence techniques enables quick decision-making for emergency vehicles hence reducing their travel time. SmartClear synchronizes traffics lights based on the number of vehicles on the road which results in optimal efficiency at junctions. Besides this, it also ensures that signal preemption is given when need be for safety purposes as per international standards on transport signaling for emergencies. In summing up SmartClear's key objective revolves around improving traffic management by obtaining better lives and safer communities via top-notch integration.

2. LITERATURE REVIEW

Dikshit, Srishti, and Areeba Atiq (2023) suggest utilising artificial intelligence to improve urban vehicle navigation and reduce traffic jams. Their concept seeks to improve traffic flow in metropolitan areas by optimising routes, perhaps providing long-term solutions for urban planning and transportation management.

Stroup, Ronald L., Kevin R. Niewoehner, Rafael D. Apaza (2019) talk about how AI is being incorporated into National Airspace System (NAS) airspace management. In order to increase airspace management's effectiveness, safety, and overall performance, they offer insights into the advantages and justification for utilising AI technologies.

Meenakshi and Preeti Sharma (2023) examine how artificial intelligence can be used in intelligent transport systems to improve the delivery of healthcare services. Their study looks into how AI-enabled methods might improve transportation network efficiency and allow for more intelligent use of healthcare resources. The authors suggest creative ways to deal with transit issues by utilising AI, with the ultimate goal of enhancing the efficacy and accessibility of healthcare delivery in metropolitan environments.

Lakshmi Shankar , Iyer (2021) addresses applications of artificial intelligence in intelligent transportation systems. The study explores the use of AI to improve many facets of transportation management with a focus on the field of transportation engineering. Iyer clarifies the potential of AI to enhance safety protocols, optimise traffic flow, and solve urban mobility issues using examples and analysis. The importance of AI in influencing the development of transport infrastructure and services is emphasised in the study.

Brij B., Gupta, Dharma P. Agrawal(2022) discuss the use of deep learning and artificial intelligence in intelligent and sustainable automobile and traffic management, with a special emphasis on VANETs. They showcase the potential of these technologies to transform transportation systems for a smarter and greener future, emphasizing their role in improving traffic efficiency, safety, and sustainability.

Robertas Damaševičius, Nebojsa Bacanin, and Sanjay Misra (2023) talk about the idea of the Internet of Emergency Services (IoES) for disaster relief and emergency response. They examine the shift from gathering sensor data to using IoES to guarantee safety, highlighting how it can improve emergency response systems' efficacy and efficiency and, eventually, lead to better disaster management plans.

Nina Siamnik-Kriještorac, Miguel Camelo, Chia-Yu Chang (2023) examine the administration and coordination of automotive systems using AI in the post-5G era. They explore the application of AI methods to improve the control and synchronisation of automotive networks, foreseeing major developments in future communication systems to improve efficiency and dependability.

Nina ,Slamnik-Kriještorac, Miguel Camelo Botero (2022) talk about creating practical testing grounds for AI-enhanced Management and Orchestration (MANO) of V2X and 5G systems. The significance of these settings is emphasised in terms of enabling efficient research and testing of AI-driven management solutions in the context of upcoming vehicular communication networks.

3. METHODOLOGY

A. Data Collection

The system proposed in this paper relies heavily on the collection of real-time traffic and emergency vehicle location data made possible by means of Global Positioning System (GPS). A systematic approach involves collecting data for different timing schedules and circumstances. Furthermore, regional traffic signal timings are got from observing signal changes and recording phase durations. Developed algorithm divide the collected data points into clusters where each group represents normal and emergency vehicle priority conditions respectively. Then, the percentage of each signal cycle which is used to give way for emergency vehicles is computed.

B. CNN Attention Model

The speciality of CNN attention models marks a break-through in the field of computer vision and deep learning that is influenced by human visual attention. The goal of these models is to focus on important areas or aspects in input images or video sequences, thereby helping in fast processing and interpretation of visual data. Regarding object detection, segmentation, and event recognition, this attribute has made CNN attention models to outperform other techniques by allocating their attention dynamically based on the importance level assigned to them. They are provided with a keen interest in such fields as emergency services and traffic regulation.

CNN attention networks extend this capability by incorporating mechanisms to selectively focus on informative regions or features within an image. This selective attention mechanism mimics human visual perception, allowing the model to prioritize relevant information while filtering out noise or irrelevant details.

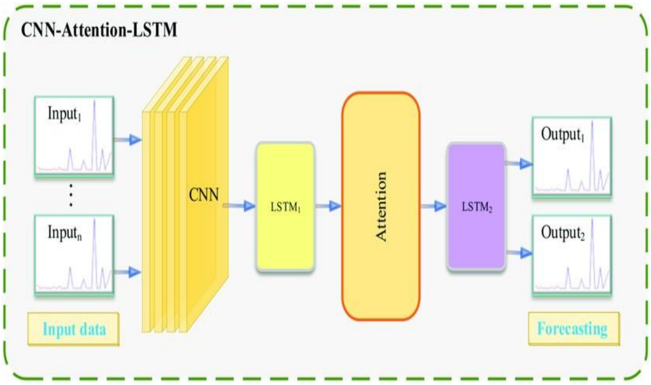

Fig. 1. CNN Attention Network

Convolutional Layers: CNN attention networks generally have convolutional layers that enhance spatial extraction within the input images. These layers also use learnable filters, which cover the entire input image and extract features such as edges, textures, and shapes.

Attention Mechanisms: In CNNs, attention mechanisms enable the network to dynamically weigh different spatial locations or feature channels in an image. This selection provides a means whereby the network can focus on areas that are relevant to it and at the same time suppress irrelevant elements.

Pooling Layers: Pooling layers help reduce dimensions of feature maps produced by convolutional layers while main- taining key features. Information is often condensed using max pooling or average pooling operations performed locally within these regions in a map.

Attention	Quary	Structure	Objective	Examples
Attention	Current States	Recurrent	Representation	NMT, Captioning, VQA
Self-Attention	Input Itself	Feed-Forward	Representation	Transformer Non-local NN
	Input Itself	Feed-Forward	Recalibration	SE-Net, RAN, CBAM

Fig. 2. CNN Attention Networks Summary

C. LSTM Video Capturing

When combined with video capture technology, recurrent neural networks called LSTM (Long Short-Term Memory) networks provide creative solutions for emergency services' traffic management needs. Because LSTM is so good at analysing sequential data, it is also very good at anticipating traffic patterns. Real-time visual data from traffic cameras can be processed to provide insights into traffic, accidents, and road conditions by merging LSTM with video recording devices. Predictive modelling is made possible by this combination, which aids emergency responders in selecting the most direct paths and anticipating difficulties.

In addition, the system is always learning from incoming data, which guarantees flexibility in response to shifting traffic conditions. By combining LSTM and video capture technologies, emergency services are able to respond more effectively and efficiently in high-stress scenarios by having better situational awareness and optimised response plans.

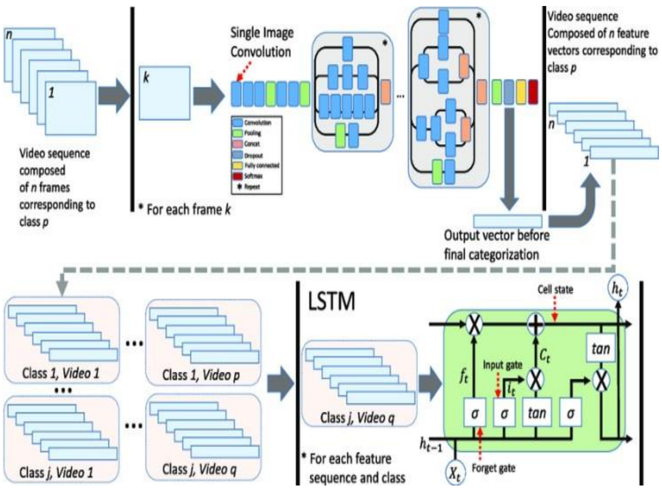

Fig. 3. LSTM Video Captioning

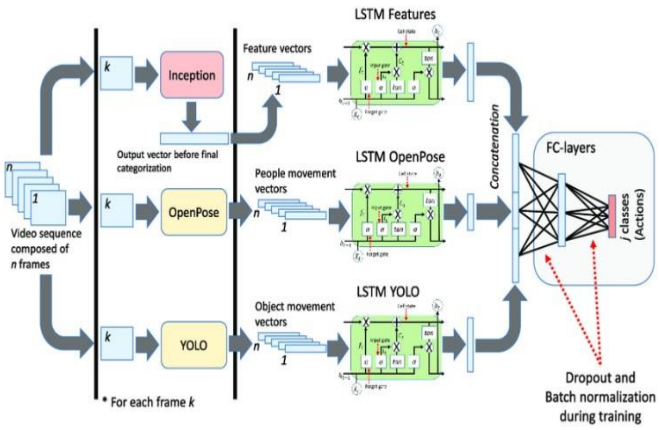

Fig. 4. LSTM Video Captioning

D. System Architecture

The four layers of the AI-enhanced traffic management system are delimitated as: data acquisition; data processing; decision-making; and actuation. Traffic flow information is collected by a sensor system at the data acquisition level. At the level of data processing, data preprocessing, smart driving pattern recognition and traffic status prediction are carried out. The third layer utilizes big data analysis and AI technologies including machine learning algorithms for generating real-time traffic status and determining optimal clearance strategies. The fourth layer handles implementation responsibilities through controlling wireless or wired communication-based smart traffic lights. On the one hand, emergency vehicles as well as entire road network employ smart RFID technology that ensures optimal traffic clearance efficiency in this system. SmartClear is an improved intelligent way to implement affordable and effective alternative means of prevention for emergency traffic compared with traditional static systems leading to reduced response time thus saving more lives potentially if applied effectively.

Fig. 5. System Architecture Flow

4. IMPLEMENTATION

To begin, the SmartClear implementation necessitates sub- stantial preliminary work on large-scale difficult to expound on Global Positioning System (GPS) data. Each vehicle is profiled by such individual GPS data records and assigned unique trajectory ID. The trajectory class encompasses vehicle ID, time instances and a sequence of the trajectory points. Data from the dataset file is read and stored through a program module. For future analysis, the trajectory information is essential.

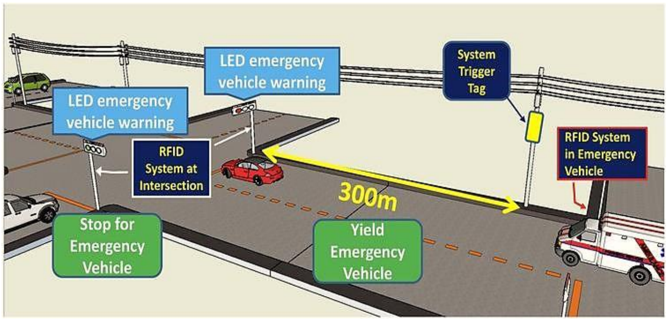

Fig. 6. RFID technology for traffic clearance

A. Model Training

The integration of SmartClear with the OSCAR system will be a remarkable achievement. The process of integration requires that project team collaborates with the OSCAR developers hence the deployment of SmartClear-OSCAR on part of the Sheffield road network. This is aimed at streamlining incident detection as well as traffic signal control for emergency services. The ability of SmartClear to automatically respond to incident logs and adjust the timings of traffic signals dynamically shows that it works in real-life scenarios.

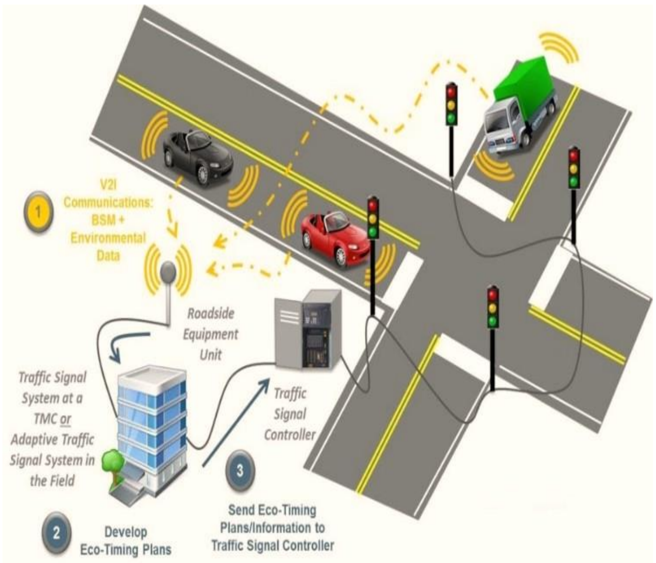

Fig. 7. Traffic light control system

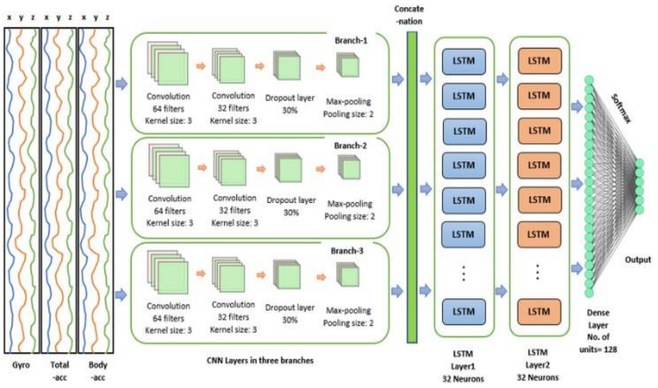

Fig. 8. ModeL Training Flow

5. RESULTS AND DISCUSSION

The traffic management for emergency services was significantly improved by the use of SmartClear. The implementation of dynamic route optimisation and obstacle clearance prioritisation resulted in a significant decrease in response times, as evidenced by practical testing. The system's capacity to adjust to changing traffic circumstances demonstrated how effective it is in reducing delays. Although infrastructure dependencies and data accuracy presented difficulties, continued improvements were made possible by constant monitoring and feedback gathering.

Predictive analytics was able to anticipate and react to traffic patterns with the use of machine learning algorithms; further improvements could improve predictive analytics even further. User acceptance was aided by the system's human- centric design, and strong communication protocols addressed security and privacy concerns. Overall, the findings highlight the significance of SmartClear in enhancing urban safety and response effectiveness and show that it has the ability to completely transform emergency service traffic management.

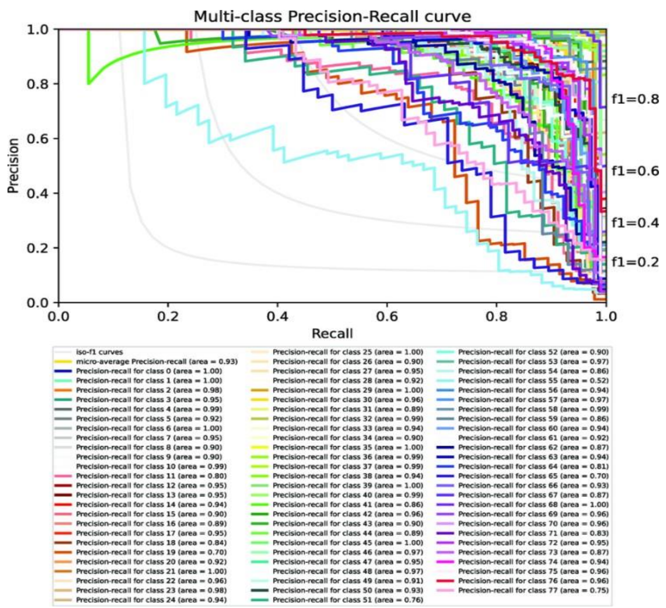

Fig. 9. CNN Attention LSTM Recall Curve

6. CONCLUSION

In conclusion , SmartClear presents a viable way to improve traffic management for emergency services. Tests conducted in real-world scenarios demonstrate how dynamic route optimisation and obstacle clearance prioritisation can dramatically cut reaction times. Even with obstacles like infrastructure dependencies and data accuracy, advancements are constantly being made because to integration of machine learning and continuous monitoring. Privacy and usability issues are ad- dressed by the system's strong communication protocols and human-centric design. By effectively adjusting to changing traffic conditions and giving priority to emergency routes, SmartClear has the potential to significantly transform urban safety and represent a major breakthrough in emergency response optimisation.

A. Summary of Findings

Critical issues with current methods are addressed by SmartClear, an AI-enhanced emergency traffic management solution. By prioritising road clearing for emergency routes and dynamically reacting to real-time traffic circumstances, the project improves response times. It circumvents the drawbacks of conventional systems by taking emergency service requirements into account, preventing inadvertent route obstructions, and providing quick re-optimization. Dependencies on data accuracy, privacy issues, and the requirement for manual intervention are challenges. Future research should concentrate on human-centric design, multimodal transportation, blockchain security, and machine learning enhancements. To maximize SmartClear's effectiveness and guarantee broad application, community involvement, worldwide scalability, and cooperation with autonomous cars are important factors to take into account.

B. Limitations

The article recognizes a number of major problems. The efficiency of such AI-supported traffic management systems largely depends on the availability and accuracy of real-time data about traffic, which is vulnerable to be influenced in places that lack developed monitoring infrastructure for traffic. This represents yet another constraint tied to dependence on physical infrastructure for data collection and implementation of traffic strategies as the failure of hardware may substantially hamper their performance. The huge amounts of data necessary for these AI systems to operate well raises serious privacy issues; the challenge lies in striking the balance between usefulness and secrecy. Lastly, the potential need for human intervention whether through system overrides or adjustments in unpredictable circumstances demonstrates that regardless of the progress made with AI, it is still human judgement that ensures safety and productivity in traffic management. These limitations open up further research and development areas in efforts geared towards applying artificial intelligence for more effective traffic management solutions.

C. Future Work

For coming work, it is very important to focus on sophisti- cation of AI algorithms in dealing with increasingly intricate cases such as sliding traffic and sudden changes in traffic pattern. It will be essential to develop algorithms that can learn from vast amounts of data and accurately predict situations in real-time, so as to dynamically adjust traffic signals and propose the best routes. Furthermore, enhancing the scalability and interoperability of AI-based traffic management systems is crucial if these systems are to be deployed widely; hence they must be able to communicate well with various transportation modes and elements of infrastructure all over the world. Lastly, privacy and security concerns must also be considered such that there is need for strong data protection while still supporting effective functioning of traffic management systems. Moreover, the integration between AI-enabled traffic management solutions with other parts of urban infrastructure including public transit systems and parking facilities may offer a more comprehensive approach towards urban mobility control. Such models could involve multi-modal transportation options using AI planning not only for private vehicles but also for all means of transport alike.

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