Mitigating Strategies for Road Accidents in Nepal using IoT, AI and ML

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ABSTRACT

Rapid deployment of Internet of Things (IoT) and increasing the number of active IoT devices connected in this network predicts 41billiondevices by 2030, double the number of devices connected now. This prominent technology is being used in every sort of applications, including transportation and traffic management systems. IoT has a significant impact on the safety road as well as accident detection and prevention systems. This paper explores the primary reasons of road accidents in Nepal, how the integration of IoT with AI solutions is embedded into vehicles to monitor and control road accidents, mitigate the number of accidents, and recommend the best IoT-enabled vehicle systems which are more compatible with the roads in mountain and hilly regions like Nepal. Mainly, sentimental analysis to observe the mind-state of the driver and alert the concerned bodies by using cloud-based services is the major concern. Later, using ultrasonic sensor and sensor boards in the sharp turn of the mountain detects another vehicle is arriving from the opposite side or any obstacles is presented nearby and suggests controlling their speed to minimize the accident is another finding. Additionally, face detection and object counting cameras, alcohol detection sensor can also reduce the road accidents by reporting real-time mistakes due to human misbehavior. Finally, the integrated effect of deploying all aforementioned technologies has been computed which seems better than individual's performance. This integrated solution can be proven milestone for reducing the number of accidents in the mountainous road system of Nepal.

1. INTRODUCTION

Nepal being mountainous country, the development of road transportation and road network is in infancy stage. The roads in the mountain region are slippery with sharp turns and difficult to navigate. Also, it has been observed that the roads in the plain region of Nepal are narrower and not managed properly. Moreover, the traffic rules and regulations are not implemented strictly. All these concerns increase the number of road accidents day by day. This is more serious problem than any natural disaster like flood, landslides and earthquake; and more people lost their life than any pandemic like COVID-19. According to police report, it has been found that 12,371 people have lost their life in vehicle accidents across Nepal within five fiscal years and more than two thousand fatalities occurring annually. During this period, 171,098 vehicles were involved in accidents. The statistics of road accidents and their consequences on fatalities and financial loss in the remaining world shows the worst situation. According to data from the World Health Organization (WHO), the global mortality rate caused by road accidents is higher than that caused by fatal diseases such as tuberculosis, diabetes, and kidney-related illnesses. It motivates to carry an extensive study about the reasons behind road accidents and preventing the loss of life and wealth using contemporary technology. Such an immense problem can be solved by integrating Internet of Things (IoT) with vehicle and transportation systems. IoT has been growing rapidly and its integration with artificial integration and machine learning (AI-ML) has fueled its diverse application. As IoT has changed every perspective of human life, safety road system and prevention road accidents can be achieved via smart IoT technology. IoT systems for road safety employ wireless sensor networks, communication modules, and predictive algorithms to detect, alert, and preventing accidents.

The statistical study by Manandhar has found poor road conditions and improper driving skill are the major factors for causing accidents in Nepal [1]. Other reasons can be overloaded vehicles, drunk and drive, weather conditions and technical problems in vehicles. Thus, it is necessary to study these factors extensively and reduce the accident frequency as early as possible. It has been observed that the road accidents can be reduced by maximizing the traffic flow by integrating artificial intelligence with real time response system [2]. In another study, Alehouse et al. [3] have developed a new protocol for vehicular ad-hoc Networks (VANETs) which minimized the frequency of road accidents and reduced the number of lives lost via accidents in Saudi Arabia. The study was conducted using simulation-based methods which revealed that the proposed protocol achieved significantly improved outcomes in comparison to existing approaches. The evaluation was carried out using key performance indicators, namely Message Delivery Ratio, Message Loss Ratio, Average Delay, and Basic Safety Message Rate, all of which demonstrated superior results under the proposed framework. It has been reported that drunk and drive is also the major reason of road-accidents. To address this issue support vector machine (SVM), a machine learning approach, is deployed reducing the number of accidents [4]. This panic situation underscores the necessity of conducting a comprehensive study on the causes of road accidents, ranging from those observed in

developing countries to those in developed and under-developed nations. In this regard, researchers and various governmental bodies have been actively engaged in this issue for a considerable period of time. Furthermore, several governments are emphasizing the development and implementation of smart traffic systems with the objective of strengthening transportation networks and reducing the rate of road accidents. Recently, Senthil et al. [5] proposed a novel framework for vehicle systems which incorporate Artificial Intelligence (AI) with Internet of Things (IoT). Mainly, this framework comprises of three modules namely: *drowsiness alert module*, *speed limitation module*, and *alcohol sensing module*. Additionally, Li-Fi technology is utilized for inter-vehicle communication due to its lower susceptibility to interference, enhanced security, and superior performance in high-density environments such as urban areas.

Table 1: Various IoT and smart technologies for safety roads and impacts.

Ref	Methodology	Technologies Used	Consequences
[2]	Experimental	Arduino board consisting IR sensors, LED lights, and buzzer	Prevent accidents at U-turns by alerting the driver
[6]	Experimental (simulation)	Smartphone sensors (accelerometer, GPS, pressure, microphone), WiFi/3G/4G, cloud	Accident detection and reporting, hospital notification
[11]	Theoreticalwith real-world data analysis	Internet of Vehicles (IoV), Roadside Units (RSUs), cloud computing, Spatio-Temporal Convolutional Long Short-Term Memory (STCLA) deep learning	Real-time accident prediction and prevention
[12]	Experimental (prototype/ simulation)	Mobile traffic sensors, IoT cloud, OpenGTS, MongoDB	Real-time traffic monitoring and alert notification
[13]	Experimental (prototype/ simulation)	Smartphone sensors (Global Positioning System (GPS), accelerometer, gyroscope)	Accident detection and classification using machine learning
[15]	Theoretical/ conceptual	Vehicle-to- Everything (V2X), edge/cloud computing, On-Board Unit (OBU), accelerometer, gyroscope, GPS, camera	Accident detection, notification, data visualization
[15]	Experimental (simulation)	Vehicle-to-Infrastructure (V2I), speed sensors (implied), RMATLAB17 simulator	Alert generation based on speed, accident prevention
[16]	Experimental (prototype)	Accelerometer, ultrasonic, limit switch, GPS, Global System for Mobile Communications (GSM), vibration sensors	Accident detection, notification, automatic braking
[17]	Experimental (prototype)	MQ3 alcohol sensor, SW-420 vibration sensor, camera, GPS, GSM, Deep Learning Convolutional Neural Network (DLCNN)	Alcohol detection, engine lock, accident prediction

Table 2: Terms and abbreviations.

Terms	Abbreviations
AI	Artificial Intelligence
COVID	Corona Virus Disease
DLCNN	Deep Learning Convolutional Neural Network
ECT	Engine Coolant Temperature
ECU	Electronic Control Unit
GPS	Global Positioning System
GSM	Global System for Mobile Communications
IoT	Internet of Things
IoV	Internet of Vehicles
LED	Light Emitting Diode
LiDAR	Light Detection and Ranging
ML	Machine Learning
OBU	On-Board Unit
RSUs	Roadside Units
STCLA	Spatio-Temporal Convolutional Long Short-Term Memory
SVM	Support Vector Machine
TPR	True Positive Rate
V2I	Vehicle-to-Infrastructure
VANETs	Vehicular Ad-hoc Networks

In the context of mountainous roads, a study by Nookala [2] explored a smart road safety and prevention system integrating Artificial Intelligence (AI), the Internet of Things (IoT), and Machine Learning (ML). The proposed system is capable of detecting weather conditions in real time and alerting vehicles to accident-prone scenarios. Moreover, it assists drivers in navigating mountain routes safely by providing real-time information and alerts regarding current road conditions and potential future hazards. Similarly, Bhatti et al., 2019 [6] developed experimental based system using plethora of in-built sensors in vehicle system which are used for accident detection and reporting the incident to nearby hospital so that injured patients got treatment in real-time. Despite of these plenty of literature, there is no any model that that incorporate face detection system for counting people (passengers), detecting alcohol consumption by driver, drowsiness sensor for driver's sleepy state and ultrasonic system for navigating vehicles into single system. That is why this model analyzes the integrated solution to fill the existing research gap. The main objectives of this paper are to analyze the performance of integrated model for safety road system alerting and notifying the traffic police and

concerning entities regarding the same. Summary of literature review is presented in Table 1.

The study is organized into four different sections. State-of-art on contemporary technologies for smart road transportation, and enhancement traffic system for mountain roads; and motivation for this research has been discussed in this section which is followed by methodology and technologies used to improve road system for mitigating accidents and saving the life to large extent. Next section highlights the results and discussion. Finally, the last section incorporates the concluding remarks and future recommendation. The list of acronyms used in this manuscript is depicted in Table 2.

2. METHODOLOGY

A comprehensive review of existing studies indicates that road traffic accidents in Nepal predominantly arise from hazardous mountain terrains, driver-related factors such as alcohol consumption and fatigue during prolonged journeys, and systemic weaknesses within traffic regulation and enforcement. To address these challenges, this paper advocates the integration of advanced smart technologies across multiple levels to strengthen road infrastructure and enhance traffic safety management. The research framework initiates with literature review of various technologies used in road traffic and management system followed by various technologies specially, wireless sensor network and IoT devices, analyzing the performance metrics and finally suggesting the integrated model with better accuracy. The detailed research framework is demonstrated below:

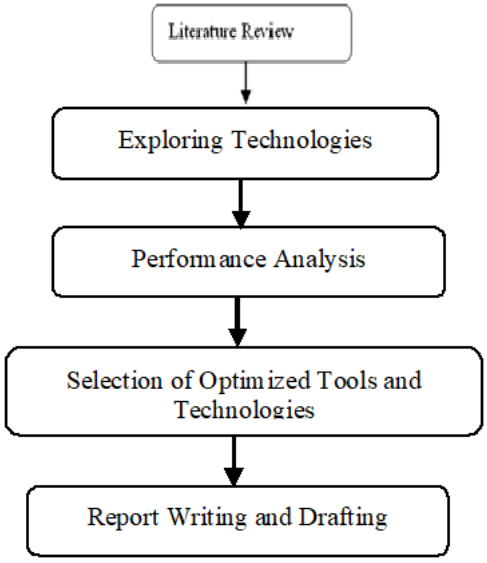

Fig. 1: Research framework for proposed model.

Main technologies and tools that used for the smart transportation and safety road systems are:

Face Detection and Counting Cameras to Enhance Traffic Systems for Vehicle Capacity Management

Face detection and counting technologies are increasingly employed in domains such as biometric authentication, security, pedestrian monitoring, and traffic management. Their integration within vehicles enables real-time monitoring of passenger occupancy and facilitates communication with nearby traffic control systems when overloading occurs, thereby reducing risks associated with excess passenger capacity. Sivaranjini *et al.* [8] proposed the use of the YOLOv9 (You Only Look Once) technique for detecting and counting faces among multiple objects.

Smart Sensors for Safe Driving and Traffic Management Systems

Drunk driving is recognized as a major cause of road accidents in Nepal. The incorporation of alcohol detection sensors that transmit real-time alerts to nearby traffic police can significantly

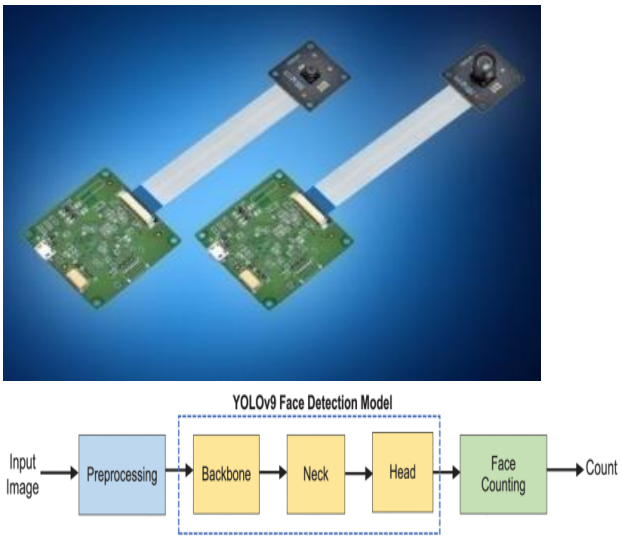

Fig. 2: Face detection camera and YOLOv9 face detection model.

reduce such incidents. Celaya-Padilla *et al.* [4] examined the use of the MQ3 sensor, which, when installed inside the vehicle, collects alcohol concentration data and employs a Support Vector Machine (SVM) classification technique to detect alcohol presence. Recently, Babu *et al.* [7] proposed a multi-sensor framework that combines an eye-blink sensor for drowsiness detection, an MQ3 sensor for alcohol consumption monitoring, and a heart rate sensor for identifying potential cardiac issues in drivers. Integrating these sensor technologies within vehicles enhances safety measures and contributes to the reduction of road accidents.

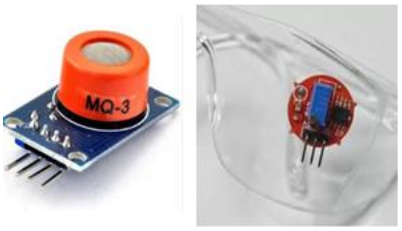

Fig. 3: MQ3 sensor for alcohol detection and Eye-blink sensor for drowsiness detection.

Environmental and Weather Sensing Devices for Navigation

Real-time monitoring of environmental conditions on mountain roads plays a critical role in traffic management and accident prevention. Mountainous routes are particularly challenging due

to sharp curves, slippery surfaces, and unpredictable factors such as humidity, lightning, and atmospheric pressure. An integrated sensing system comprising cameras, temperature sensors, moisture scanners, and

LiDAR can provide comprehensive information on road conditions, including temperature, humidity, visibility, and surface status [10]. Moreover, LiDAR technology can detect oncoming vehicles and issue alerts to drivers, thereby reducing the likelihood of collisions.

Fig. 4: Arduino board with IR sensors, LED, and buzzer to detect obstacles from opposite.

These sensor-based technologies represent a significant advancement toward enhancing road safety and reducing accident rates, particularly in mountainous regions like Nepal. The detail of experiment results, accuracy, and test-train ratio based on secondary data has been illustrated below:

Table 3: Performance analysis of different sensors in road traffic system.

Sensors	Methodology	Accuracy	Remarks
MQ3 sensor [8]	80:20 (ML model)	0.98	Detects alcohol consumption by driver
Face detection sensor [9]	Empirical study	0.98	Counts the passengers inside vehicle and reports to the nearby concerning body
Eye-blink sensor [8]	Experimental study	0.95	Alert the drowsiness of driver (more than 4 seconds)

3. RESULTS AND DISCUSSION

It is important to compute the accuracy of integrated solution in vehicle where all these sensors are included. For this computation fusion rule has been used assuming all three sensors are independent. Let sensitivities (TPR) for these sensors are s_1, s_2, s_3 and specificities (TNR) are t_1, t_2, t_3 respectively, the combined sensitivity can be,

$$Combined\ True\ Positive\ Rate\ (TPR) = 1 - (1 - s_1)(1 - s_2)(1 - s_3) = 99.998\%$$

However, if two of these sensors will be triggered out of three, the combined sensitivity (TPR) will be,

$$P_3 = 0.98 \times 0.98 \times 0.95 = 0.912$$

$$P_2 = (0.98 \times 0.98 \times 0.05) + (0.98 \times 0.02 \times 0.95) + (0.02 \times 0.98 \times 0.95)$$
$$= 0.04802 + 0.01862 + 0.01862 = 0.08526$$
$$\text{TPR (majority)} \approx 0.08526 + 0.912 = \mathbf{0.99726} \ (\approx 99.7\%)$$

Results reveal that the performance (TPR) of the integrated system will be approximately 99.98% when these sensors work independently and 99.7% when two of the sensors will be triggered.

The rapid advancement and deployment of IoT devices across diverse sectors now make it feasible to transform conventional road systems into smart, safety-focused traffic networks. Vehicles equipped with advanced sensor technologies provide significant opportunities for fault detection, navigation, and safe driving, irrespective of road conditions. Furthermore, smart road systems offer benefits to both governmental authorities and the public, enabling efficient traffic monitoring through Wi-Fi–enabled sensor networks and enhancing overall road safety.

As a mountainous country at the early stages of digital development, Nepal faces significant barriers to implementing smart city and smart road initiatives, with the digital divide being a primary constraint. Another critical challenge lies in the system's implementation, as neither transportation companies nor government agencies consistently ensure fair monitoring. Additionally, the presence of bureaucratic corruption further restricts effective deployment. A large portion of existing transportation infrastructure relies on traditional models, making the transition to smart systems is complex and resource-intensive.

4. CONCLUSION

The integration of smart technologies into vehicles and road traffic systems offers a promising pathway to reducing accidents and ensuring sustainable road safety management. Sensors embedded at various levels from drivers' wearable to vehicle components, enable continuous monitoring of driver behavior, passenger load, and mechanical performance, while ultrasonic sensors enhance safety in low-visibility mountain roads. In the context of Nepal's challenging geographical and infrastructural conditions, configuring vehicles with ultrasonic sensors, face detection and passenger-counting systems, and alcohol detection technologies can substantially mitigate accident risks. The adoption of such IoT-enabled solutions not only enhances driver and passenger safety but also strengthens the overall reliability and sustainability of the road transport system. Experimental study in the context of Nepal and evaluating the actual performance of the model is the future recommendation.

AUTHOR CONTRIBUTION

The whole work was carried by PD Bhatt.

DECLARATION OF CONFLICT OF INTEREST

The author declares no known conflicts of interest.

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