

Economical Infotainment Solution Augmented with Advanced Telematics for Collision Detection, Vehicle Localization, and Real-time Health Status Monitoring

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Abstract: The global tally reveals approximately 1.3 million fatalities due to road traffic collisions. Numerous accidents have occurred unattended at roadside locations due to the lack of access to essential emergency services. In scenarios where accidents transpire in sparsely populated areas or when a lone passenger loses consciousness, the critical time window for crucial medical intervention often elapses without the possibility of summoning aid. Considering these multifaceted challenges, the necessity arises for a cost-efficient system adept at promptly detecting collisions and notifying emergency services. This paper proposes a comprehensive system imbued with versatile functionalities. It encompasses collision detection, real-time monitoring of the health status of injured parties through integrated sensors, employment of cameras, 3G/4G technology, and an autonomous infotainment system. This system operates autonomously from the vehicle network, initiating emergency responses.

Keywords: Road Traffic Collisions; Collision Detection; Real-Time Monitoring; Integrated Sensors; 3G/4G Technology; Autonomous Infotainment System; Vehicle Network; VIAAN System; Information Technology.

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1. Introduction

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In 2018, the World Health Organization (WHO) issued a Global Status Report [1] on road safety, divulging a deeply concerning annual toll of 1.35 million road traffic fatalities. Astonishingly, road traffic injuries have now ascended to become the leading cause of death for individuals aged 4 to 30. Particularly pronounced in developing nations, these injuries disproportionately burden their populations. The report underscores that while mobility remains essential, the price paid in terms of road traffic injuries and deaths is egregiously high, especially when effective preventative measures are within reach. The report ardently advocates for swift and resolute action to implement these measures, striving to meet global targets and ultimately preserve lives. Swift medical intervention at the scene of an accident can often be the difference between life and death. Many accidents occur in challenging terrains such as mountainous regions and steep curves. In countries like India, no automated mechanism exists to trigger emergency services upon road accident detection. Typically, survival relies on the goodwill of a “Good Samaritan” who takes it upon themselves to alert emergency services.

In economically developing nations, traffic accidents exhibit a staggering 90% fatality rate. Precision in patient care, particularly for accident victims, is paramount. Addressing the injured before hospitalization hinges on two critical timeframes: the “golden hour” and the “platinum 10 minutes” for the patient. The “golden hour” denotes the pivotal first 60 minutes following an accident, during which receiving definitive medical attention is paramount, as the risk of adverse outcomes escalates significantly thereafter. Within this timeframe, paramedics must immediately treat seriously injured patients, specifically within the “platinum 10 minutes,” a subset of the “golden hour,” to maximize survival probabilities. Despite extensive research into patient survival rates across various injuries, a study in the United States focusing on car accidents revealed an escalating fatality rate corresponding to prolonged on-site patient presence [2]. Comprehending the various dimensions of the issue, the necessity arises for a portable and economically viable solution that transcends vehicle classifications. The VIAAN system (Vehicle Independent Accident Detection and Alerting Node) has been introduced, amalgamating the principles of Telematics and Infotainment to achieve its functionality. In this context, telematics integrates telecommunications and informatics, facilitating the seamless transmission, storage, and retrieval of information between devices and remote objects through networked communication and information technology.

The VIAAN system is meticulously crafted to identify road accidents and promptly trigger emergency responses. Its architecture includes various components such as sensors for monitoring vehicle and driver parameters, a camera module, wireless network capabilities, and dedicated emergency response units. Importantly, it is engineered to operate autonomously from the vehicle's internal networks, rendering it adaptable for use across various mobile platforms, regardless of automotive battery voltages. In the event of an accident, the sensors diligently assess car parameters while considering input from a heart rate sensor linked to the driver's seatbelt, thereby assessing the likelihood of an accident or emergent situation. The integrated camera captures post-accident images of the injured parties. Wireless networks are pivotal in pinpointing location data and triggering swift emergency interventions. To facilitate prompt responses, dedicated emergency response units are crucial for executing rapid actions upon receiving alerts about incidents.

2. Literature Survey

Numerous research endeavours have been dedicated to advancing Vehicle Tracking and Accident Detection systems. This section delves into various scholarly papers addressing the concept of intelligent and efficient vehicle tracking and the establishment of rapid-response systems. Some prominent studies in this field encompass precrash prediction and collision event identification, as evidenced by previous works [3] through [4]. Notably, Chan [5] extensively explored system-level design patterns while envisioning future potentialities for automotive restraint systems. The study also identified emerging trends in collision recognition and passenger protection technologies. Jukkala et al. [6] introduced an advanced driver assistance system (ADAS) featuring active and passive safety components for collision prevention and rider safeguarding. In contrast, Kawasaki et al. [7] scrutinized the precision of V2X communication in incident warning systems employing LTE technology. Investigation [8] entailed a comprehensive survey of cooperative precrash applications utilizing range sensors.

Meanwhile, Thammakaron and Tangamchit [9] meticulously assessed the response times of installed front collision warning systems in vehicles, introducing warning delay as a performance metric. Research focused on developing an intelligent transportation system prioritizing safety measures that foster collaboration between vehicles and roadway infrastructure to avert collisions. In a different exploration, Ito et al. [10] employed driving recorder data analysis to scrutinize variations in side-impact car-and-cyclist accidents and adjacent collisions. A groundbreaking scoring methodology for a crash-imminent braking system in a 2011 model passenger car was devised by Chien et al. [11], encompassing a spectrum of test outcomes such as true-positive, true-negative, false-positive, and false-negative results.

In the context of the European Union (EU), the eCall initiative [13] aimed to minimize major traffic accidents by mandating the implementation of emergency phoning services that automatically contact the nearest Public Safety Answer Point (PSAP) through airbag deployment. Jiang et al. [3] contribution introduced a heterogeneous network-based highway accident alert system reliant on interactive communication across diverse networking devices. Kantawong and Phanprasit [12] innovatively

developed a smart traffic cone system employing radiofrequency identification (RFID) technology for road and pedestrian detection. For precise vehicle crash detection, Supriya et al. [13] proposed a multisensor decision fusion technique leveraging inputs from various sensors, including accelerometers and airbag deployment sensors.

Scanlon et al. [14] delved into the feasibility of early recognition for events such as left turns, cross-paths, and opposite-direction crashes. Hirai and Murase [15] introduced a communication architecture founded on V2X communications and node clustering for crash warnings. Scanlon et al. [14] research harnessed real-world intersection crash data to model driver acceleration behaviour, revealing distinct acceleration patterns in precrash scenarios. Lai et al. [16] innovative approach integrated an AdaBoost-based cascade classifier into a forward-facing smart crash warning system, enhancing performance through vision-based vehicle identification and a fusion of machine learning and deep learning techniques.

As detailed by Scanlon et al. [14], integrating smartphones within cars is a common practice, often placing them near the vehicle. In severe collisions, where the vehicle accelerates at approximately 60 g, it has been observed that dropping a cell phone from a height of one meter or more could result in data collection beyond the detection range of its onboard accelerometer. The Sharma S-Car Crash system represents a self-contained accident detection mechanism that harnesses the capabilities of smartphones. This system gathers data to effectively monitor various parameters by employing a combination of intrinsic sensors, including GPS receivers, accelerometers, magnetometers, and gyroscopes. It meticulously tracks axial velocities of moving entities and swiftly triggers alarms in the presence of anomalies. Notably, Scanlon et al. [14] explain that S-Car Crash's collision algorithms establish thresholds based on three-axis accelerometer data. The comparison of products in the market with the proposed system is shown in Table 1.

Table 1: Comparison of products in the market with the proposed system

Function/Features	Deep Crash	Dash Cam	VIAAN
GPS	Yes	Yes	Yes
Driving Video Recording	Yes	Yes	Provision Added for live monitoring
Collision Detection	Yes	Yes	Yes
Abnormal Acceleration detection	Yes	Yes	Yes
Connectivity	USB, BT,3G/4G	BT	Ethernet (SNVC), BT, USB, WIFI, 4G
Could be based	Yes	No	Yes
Web management platform	Yes	No	yes
E-call	Yes	No	Yes
Emergency Notification	Yes	No	Yes
Driver Health Monitoring	No	No	Yes
Other	Development Cost is high	Development Cost is high	Development costs are low

3. Proposed VIAAN System

VIAAN operates in real-time and is equipped with emergency alert capabilities to aid individuals involved in accidents. Importantly, the system functions independently of the vehicle networks employed within a car. The framework of VIAAN is structured around three distinctive layers: the Sensing Layer, the Network Layer, and the Application Layer. Figure 1 shows the framework of these three layers. VIAAN operates through three primary layers: the Sensing Layer, the Network Layer, and the Application Layer, each contributing to its comprehensive functionality.

3.1. Sensing Layer

The Sensing Layer has Three-Axis Sensors that meticulously capture sudden and unusual accelerations and significant collisions. Such occurrences impact the vehicle's motion, potentially causing deformations in the automotive chassis. The Heart Rate Sensor constantly monitors the driver's heart rate, recognizing that the anticipation of a collision triggers reflex actions that significantly elevate heart rates.

The Heart Rate Sensor data, transmitted via a Bluetooth Low Energy (BLE) device connected to the seat belt, is an alert mechanism for detecting the driver's abnormal health. The GPS Module, interfaced with the system, shares the vehicle's current location after the sensors identify potential collision scenarios. All these sensors, excluding the Heart Rate Sensor, are directly linked to the microcontroller.

3.2. Network Layer

As projected by BI Intelligence, the global market for connected cars is poised for rapid growth, with a compound annual growth rate of 35% from 2016 to 2021, amounting to 94 million units. This signifies that around 82% of vehicles will have connectivity by that time. The sensor-collected information is transmitted to the processing unit via wired and wireless technologies. Car telematics' importance has surged recently due to the integration of intelligent safety systems, networking capabilities, and autonomous driving technologies. This trend is anticipated to persist, and a dedicated telematics platform facilitates easy connection within the heterogeneous vehicular network.



Figure 1: System framework

3.3. Application Layer

The Application Layer encompasses a web server that stores accident information, including location details and passenger images captured by the integrated camera. The Blynk server and platform visualize accident detection and sensing data. This platform supports both web and mobile applications. This layer ensures that wireless device-transmitted data is structured to capture events in a database format, facilitating further analysis. This data could also be employed to process insurance claims for passengers in the vehicle. Notably, studies have indicated that 205 accidents were attributed to drivers' improper health conditions, leading to the unfortunate loss of lives. VIAAN is a comprehensive system that seamlessly integrates these layers to provide real-time accident detection, health monitoring, and emergency response functionalities, significantly improving road safety and passenger well-being.

The Three Axis Sensors are adept at capturing sudden and atypical accelerations and significant collisions that could impact the vehicle's actual motion. These collisions may lead to chassis deformations in the automotive structure. Monitoring the driver's heart rate is achieved through a Heart Rate Sensor, continuously ensuring the driver's well-being. Notably, studies have indicated that the driver's heart rate increases significantly due to reflex reactions when the possibility of a collision is perceived. The data transmitted via the Bluetooth Low Energy (BLE) device connected to the heart rate sensor, which is affixed to the seat belt, raises alerts about the driver's abnormal health condition. A GPS module integrated into the system is pivotal in sharing the vehicle's current location once the sensors detect all potential collision scenarios. While all sensors, except the Heart Rate Sensor, are directly interfaced with the microcontroller, the Network Layer employs wired and wireless technologies to transmit the collected data to the processing unit. The block diagram of telematics with a web application is shown in Figure 2.

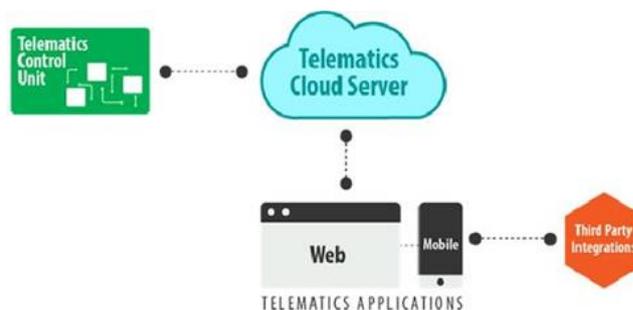


Figure 2: Telematics + Web application

The data captured by the Sensing Layer undergoes analysis within the Real-Time Operating System (RTOS) framework. Upon detecting unusual activities, the system triggers emergency responses, such as sending an SMS with the vehicle's location details, capturing passenger images, measuring the driver's heart rate, and forwarding this information to the back-end support team. This team can then prepare appropriate emergency responses based on the number of passengers in the vehicle. The flow chart of the proposed VIAAN system is shown in Figure 3. Table 2 shows the specifications of the VIAAN system.

Table 2: Proposed VIAAN system specifications

Item	Description
CPU	ARM® 32-bit Cortex®-M7 CPU with FPU
RAM	128Mbit SDRAM
FLASH	128Mb QSPI Flash
Camera	8M Pixels
LCD	RGB LCD TFT WITH 888 CONFIGURATIONS
OS	RTOS

VIAAN also has a Human-Machine Interface (HMI) system for user interaction. This HMI features a 4.3-inch TFT Display with capacitive touch capabilities. The display's user interface is developed using the Touch GFX Feature from ST-Microelectronics, which is interfaced with the microcontroller via an RGB interface. The HMI offers multiple screens and features for user interaction:

- **Audio Player:** The system can play audio from external drives, utilizing an integrated HS-USB port and an AUDIO CODEC for audio output.
- **Audio Recorder:** The system includes an audio player option, leveraging the USB port and SDRAM to process audio data. Currently, the player supports WAV files.
- **Home Automation:** This feature allows users to control home features such as lights, water heaters, and water tank supplies. The system also enables remote monitoring of various rooms in the home, enhancing convenience and security.
- **Vehicle Details:** The Vehicle Information icon displays pertinent features like temperature inside the vehicle, speed, and the driver's health status.

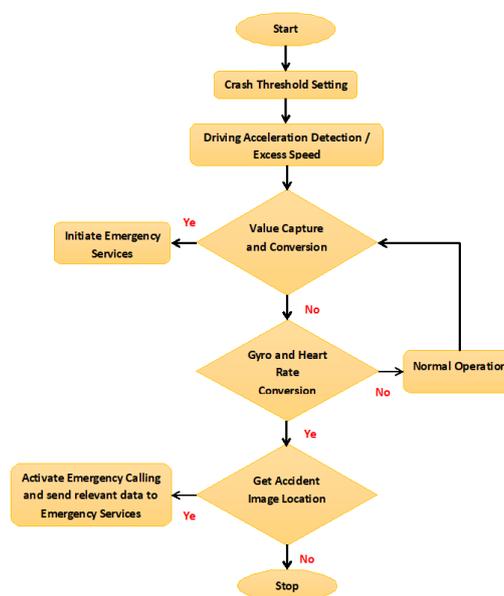


Figure 3: Flow chart of the proposed system

3.4. Driver Health Monitoring

This section provides real-time updates on the driver's heart rate and related parameters. The system process is executed according to an algorithm illustrated in the image below.

3.5. High-Speed Collision Criteria

Referring to IIHS data analysis, high-speed collisions encompass instances where the instantaneous acceleration exceeds 4 g, and the average vehicle speed exceeds 80 km/h. The outcomes of this comprehensive analysis inform the established thresholds for identifying high-speed single-vehicle and head-on collisions.

3.6. Application Layer

Situated within the Application Layer is a web server that stores a comprehensive record of accident-related information. This encompasses details of the accidents, including precise location information and images of passengers captured by the onboard camera. The Blynk server and platform are central in visualizing accident detection and sensing data. This platform serves both web-based and mobile applications. Ensuring robust data management, the layer is designed to meticulously capture data transmitted by wireless devices in a specific format. This meticulous formatting facilitates the comprehensive capture of all events in a database structure, enabling subsequent in-depth situational analysis. The captured data holds potential for applications such as processing insurance claims for passengers within the vehicle.

3.7. Safety Studies and Driver Health

Research focused on passenger safety during vehicle travel underscores the pivotal role of driver health. Notably, 205 accidents were attributed to improper driver health conditions, leading to tragic losses of life. This underscores the importance of proactive measures, such as advanced systems like the one presented here, to ensure the well-being of all vehicle occupants.

4. VIAAN system architecture and prototype

The system incorporates a 32-bit ARM® Cortex®-M7 CPU with an FPU (Floating Point Unit) and a versatile real-time accelerator. This configuration enables robust high-level data processing capabilities. Functioning as a controller device, the controller manages data collected from multiple interfaces. It is further enhanced with an L1 cache, encompassing a 4KB data cache and a 4KB instruction cache. Operating at a frequency of up to 216 MHz, the controller features an MPU (Memory Protection Unit), offering a performance of 462 DMIPS (Dhrystone Million Instructions Per Second) or 2.14 DMIPS per MHz. Additionally, it supports DSP (Digital Signal Processing) instructions. Figure 4 shows the architecture of the VIAAN system.

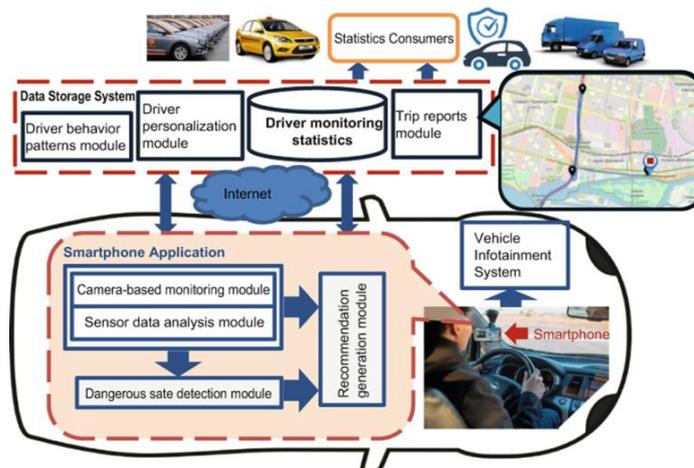


Figure 4: VIAAN system architecture

These advanced attributes facilitate seamless execution with zero-wait states from embedded Flash memory and external storage. The controller also boasts compatibility with diverse interfaces, including RGB TFT Display, USB Drivers, and Audio and Video functionalities. As the system's central hub, the controller is the front end, adeptly managing the complete user interface and system functionalities. These encompass a wide spectrum: Audio, Video, Display processing, and more. The system design has been meticulously crafted to be universally compatible with all vehicle types, irrespective of their battery voltage (Low Motor Vehicle or High Voltage), and is shown in Figure 5. This design features two distinct input sources: the primary one is the vehicle's battery input, while the secondary source is a USB input. Integral to the system's architecture are three key power supplies. The foundational power sources for the entire design are the 5V and 3.3V supplies. To ensure seamless functionality across an extensive operational span ranging from 8V to 36V and to cater to power supply demands of up to 6A, the LM63460 Buck converter from Texas Instruments has been carefully chosen. Thorough consideration was given

to ascertain the power supply current, involving a comprehensive evaluation of power consumption across all system components during operational phases. Rigorous testing protocols were enacted to validate the actual performance of the DC-DC Converter. These tests ensured the system could operate effectively within an expansive operational range, maintaining peak efficiency across specified design parameters.

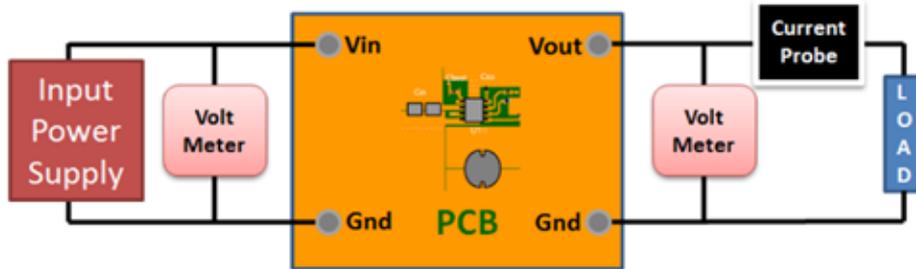


Figure 5: Test setup

The test results ensured the operation of the converter over the wide operating range and support efficiency greater than 90% in the specified region of operation. 3.3V is supplied to the system via an LDO, with minimal losses and a minimum drop supply of up to 500mA of currents to the peripheral operating system. Figure 6 provides a depiction of the setup utilized to demonstrate the system's functionality, incorporating components such as the STM32F7 series EVK, assorted ESP32 modules, and a 4G module. The first element showcased in the illustration is the ESP32 board, which is equipped with a 4G module for detecting accidents and sensor functionalities. The board has a 4G antenna for communication SIM card slots and is powered by a USB connection. A secondary ESP32 board, acting as an MCU, monitors the driver's heart rate and could be extended to include co-passengers. This board communicates with the primary ESP32 via Bluetooth Low Energy (BLE) to transmit sensor data. The primary ESP32 is linked to the STM32 MCU EVK, facilitating data communication for display on the UI or integrated TFT display.



Figure 6: Experimental setup

The Blynk platform serves as the web platform for data transmission and display, with attributes allowing direct data presentation from the controller. The platform includes a mobile app for IoT operations, such as data exchange with the cloud. While similar systems exist, the focus here is on cost-effectiveness and accessibility. Operating as a real-time system with schedulers, the design was tested extensively, demonstrating that the Primary ESP32 promptly detects and transmits sensor data. Conducted over 20 iterations, the comprehensive test verified system functionality. The left image displays the system in operation, incorporating vehicle speed and inputs from the accelerometer and gyroscope. Heart rate monitoring ensures the driver's fitness for driving. The Blynk platform captures data the RF controller sends through Wi-Fi and presents it in a portal. Sensor data updates swiftly in the system. The design also triggers emergency calls and SMS alerts, with captured sensor data displayed on the forum, including speed, heart rate, GPS coordinates, and in-car images. The system employs sensors like the accelerometer, gyroscope, and heart rate sensor to collect vehicle and driver health data, as shown in Figure 7. It enacts emergency responses based on sensor alerts, utilizing the 4G module to trigger calls and messages while also uploading data to the Blynk platform. It serves as the cloud platform for development purposes.

Upon detecting driver drowsiness, the system initiates an alert by playing repetitive voice prompts and sending an email notification to the vehicle owner or relevant authority. A speech speaker is employed instead of a traditional buzzer for enhanced attentiveness. If the voice alert proves ineffective, the owner can provide further warnings after receiving the email, as depicted in Figure 8. Unintentional driving or drowsiness can lead to serious road accidents, emphasizing the need to assess the severity status via sensors.



Figure 7: Data displayed on the web portal

Equally critical is the ability to swiftly determine the accident's location to enable urgent medical services. Hence, an emergency message is dispatched to a nearby hospital authority and the vehicle owner to ensure timely precautions. This message is retrieved from a dedicated web portal, presenting concise accident data, as demonstrated in Figure 9.



Figure 8: Mobile alert: email notification received

The web page utilizes Glassfish local server (JSP page) technology and supports managing multiple accidents occurring within a similar timeframe. Once the collision location is pinpointed via the web portal, it is visually represented on a map link, exemplified in Figure 10. This map employs a green bar to indicate the source or traced location and a red bar to indicate the incident's destination or severity.

impact_severity	latitude	longitude	time	location_pincode	google_maps_pos
high	20.4377	85.8997	2020-04-17 22:45:25	753013	https://www.google.com/maps/@20.4377008,85.899782,15z
medium	20.4377	85.8997	2020-04-17 22:45:25	753013	https://www.google.com/maps/@20.4377008,85.89981,15z
medium	20.4377	85.8997	2020-04-17 22:45:25	753013	https://www.google.com/maps/@20.4377008,85.89981,15z
high	20.4377	85.8997	2020-04-17 22:45:25	753013	https://www.google.com/maps/@20.4377008,85.89981456,15z

Figure 9: Web page display of data from collision impact measurement system

This study conducted experiments involving five individuals exposed to various conditions, including wearing glasses and an alternate view without glasses. The assessment focused on multiple aspects, particularly eye and drowsiness detection accuracy. Blinking eyes and drowsiness were detected using 50 frames selected to observe accuracy within video streams.

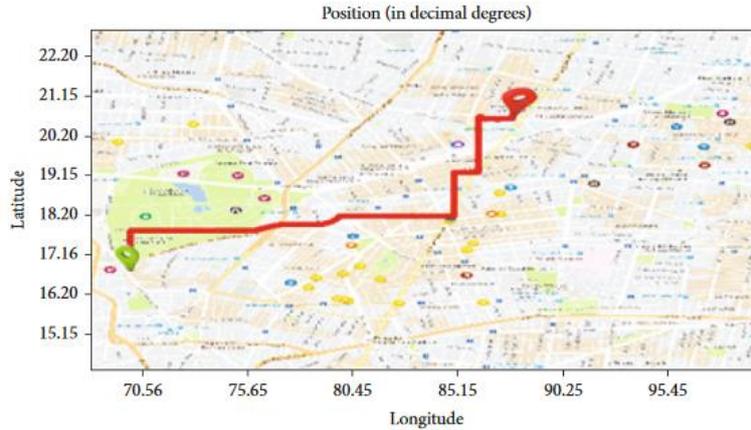


Figure 10: Collision location mapping on the map

The comprehensive analysis encompassed frames categorized as Positive Detection of Eye (PDE), Negative Detection of Eye (NDE), Positive Detection of Alarm (PDA), Negative Detection of Alarm (NDA), Positive Detection of Mail (PDM), and Negative Detection of Mail (NDM). Utilizing the data presented in Table 3, eye detection and drowsiness detection accuracy can be precisely calculated based on the provided dataset frames across various scenarios. The accuracy in eye detection is denoted as AED, while the accuracy in drowsiness detection is represented as ADD in equations (1) and (2).

$$AED = \frac{PDE}{PDE+NDE} \quad (1)$$

$$ADD = \frac{PDA+PDM}{PDA+NDA+PDM+NDM} \quad (2)$$

Table 3: Performance analysis of the proposed system

Face Gesture	PDE	NDE	PDA	NDA	PDM	NDM	AED	ADD
With Eyewear	48	2	46	4	47	3	96%	93%
Without Eyewear	49	1	48	2	47	3	98%	95%
Different Perspective	47	3	46	4	46	4	94%	92%
Total	144	6	140	10	140	10	96%	93%

In conclusion, from the comprehensive test analysis, it is evident that the utilization of facial landmarks remains consistent across different conditions, consistently outperforming the cascaded method in accuracy. However, it is noteworthy that this process experiences slightly longer loading times during deep night vision than the cascaded technique. Consequently, leveraging the facial landmark method, the proposed system offers an effective and successful approach to drowsiness detection. Furthermore, it presents an additional interface for detecting collisions caused by drowsiness or the driver's unconscious state. The system was rigorously tested on a diverse group of 10 individuals encompassing various scenarios. Drowsiness detection was accompanied by a vocal alarm and an associated email dispatched to the owner or relevant authority. Concurrently, random data sets were subjected to the system to assess its functionality, yielding a remarkable accuracy rate of 96%. This impressive performance substantiates the system's potential for effectively monitoring driver fatigue and collision impacts, enhancing its practicality and value.

5. Conclusion

This research paper introduces the VIAAN system, which integrates sensors and interfaces into a closed-loop configuration. The primary objective of this design is to establish a universally applicable system, named VIAAN, tailored for all four-wheeled vehicles, regardless of their battery voltage. This system is pivotal in effectively detecting accidents and initiating prompt emergency services. Moreover, it incorporates supplementary functionalities to augment driver safety. The study proposes an active monitoring system that efficiently gathers pertinent data for diverse automotive applications, regardless of the specific vehicle type. The system comprises a compact in-car entertainment device, a telematics platform integrated with collision avoidance sensors, and a cloud-based administrative interface. The system is intricately crafted to ensure that the integrated sensors capture relevant data, subsequently processing it to dispatch emergency services to the accident site within the critical time window. Upon a traffic collision occurrence, the system expeditiously relays essential information to the cloud-based

management platform. This immediate transmission enables swift emergency notifications and streamlines ensuing procedures. On an average scale, the time required for emergency-related alerts to travel from the vehicle to the cloud-based platform is within the millisecond range. This rapid reaction time guarantees the execution of timely measures during emergency scenarios.

5.1. Future Work

In the forthcoming years, efforts will be dedicated to elevating the recognition accuracy of the system through the enhancement of the training model and an expansion of the training dataset. Addressing the complexities of establishing sensor thresholds for high-speed head-on and single-vehicle crashes solely based on acceleration, gyroscope, and heart rate will also be explored. Future research endeavours will aim to refine the methods for sensing traffic incidents and refining the thresholds presented in this study, derived from a prior investigation. A comprehensive examination of driver behaviour will be conducted to optimize the deployment and integration of the cloud-based management server. Particularly in scenarios involving high-speed head-on and single-vehicle crashes, the cloud-based management platform, equipped to gather GPS location and other pertinent information, could be employed for seamless information exchange with nearby rescue units, thereby minimizing response times. It's essential to highlight that the current study did not directly address privacy and anonymity concerns. Future initiatives will be concentrated on resolving these issues and establishing appropriate safeguards to maintain anonymity and privacy within the system.

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Conflicts of Interest Statement: The authors confirm that there are no conflicts of interest related to this study. All sources used have been properly cited.

Ethics and Consent Statement: Ethical approval was obtained, and informed consent was received from both the organization and individual participants involved in data collection.

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