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IoT-Based Smart Accident Detection and Early Warning System for Emergency Response and Risk Management

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***Abstract*—Driving in dense fog creates significant challenges, particularly in Asian countries like Pakistan, where increasing traffic and air pollution contribute to reduced visibility, elevate the risk of accidents, property damage, and fatalities. Accidents in such conditions are worsened by vehicle congestion and poor weather, such as dense fog. To address these issues, this study proposes an IoT-based intelligent accident detection and early warning system that uses integrated smartphone sensors to detect and monitor vehicular collisions. The system enhances risk management by autonomously detecting accidents and instantly transmitting essential information, including precise location, to emergency response networks for timely intervention and decision-making. Additionally, the system alerts driver to possible near-collisions or hazardous conditions through real-time warning alert, displayed via the Blynk application. Utilizing a smartphone's built-in sensors to detect vehicular collisions and notify the nearest first responders, along with providing real-time location tracking for paramedics and emergency victims, can significantly enhance recovery chances for victims while reducing both time and costs. The operational reliability and accuracy of the IoT-based framework for smart transportation are evaluated through numerical and simulation-based experiments, validating its efficacy in harsh environmental conditions.**

Keywords*—IoT; Blynk application; smart transportation; accident detecting and early warning system; risk management

I. INTRODUCTION

The performance of traffic systems can be significantly enhanced by implementing an advanced, automated algorithm that integrates various sensors to collect and transmit data through the IoT. To optimize its functionality, the automated traffic control system must differ from traditional methods, utilizing real-time data processing to improve traffic flow and safety, particularly in poor weather conditions such as dense fog and haze [1]. Previous studies indicate that victims' odds of surviving an accident might rise by as much as 6% when crash reaction time is shortened by one minute. About 55% of the world's population live in cities as of 2024, and by 2050, that percentage is expected to increase to 68%. Increasing traffic congestion is a result of this urban expansion [2]. Hence, enhanced road safety measures are emphasized by the fact that delays can be fatal. IoT powered Intelligent Transport Systems offer a potential solution, with Vehicular Ad-hoc Networks playing a central role. These networks use vehicles as communication nodes, enabling accident detection and issuing alerts through radio modules. Responders are notified via sensor-based detection, mobile network messaging, and GPS location tracking [3]. Transport systems have changed as a result of the quick development of IoT and 5G technologies, which have improved user experience and safety efficiency. IoT enhances traffic flow, minimizes accidents, and improves toll collection automated ticketing, real-time tracking, and passenger information systems make traveling on transportation easier and safer. The integration of emerging technologies, designed to address and overcome significant challenges, enhances system efficiency and facilitates innovative solutions across various domains [4]. Such as smart healthcare, smart cities, and intelligent transportation [5]. By utilizing MEMS sensors, Raspberry Pi, GPS, and GSM technologies, the system detects vehicular accidents and collects relevant data, including vehicle details, victim information, and a Google Maps link of the accident location. This information is swiftly transmitted to the nearest police station, family members, and hospital [6]. The system also identifies the nearest responder to expedite arrival at the scene, thereby decreasing fatalities caused by accidents, improving treatment response time, minimizing traffic disruptions, and ensuring efficient accident and risk management [7]. In dense fog conditions, the system employs advanced image processing and sensing techniques to enhance safety. It employs the Dark Channel Prior (DCP) algorithm for foggy video processing and guided filtering for dehazing, while a time-of-flight (ToF) sensor with a 15-meter detection range is utilized for real-time obstacle identification and performance evaluation through Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index Measure (SSIM) metrics demonstrated the system's effectiveness in improving road safety under low-visibility condition [8]. The Convolutional Autoencoder Aided Detection (CAaDet) framework provides a basis for the development of secure Internet of Vehicles (IoV) systems [9]. By employing a deep learning-based anomaly detection approach, which enhances detection precision while minimizing false alarm rates, thereby improving the reliability, security, and overall performance of IoV systems in complex and dynamic traffic conditions [10].

To enhance emergency response and reduce fatalities, resent studies integrate IoT with GPS tracking to determine the accident location, while SOS calls are made to nearby hospitals

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and emergency services. Additionally, alerts are sent to responsible authorities to ensure timely assistance [11]. An Intelligent Transportation System (ITS) approach using connected vehicle technology to address issues of traffic congestion, fatalities, and accidents. Using IoT and cloud infrastructure, the system monitors vehicle locations in real time [12]. Traffic data is collected using sensors and cameras, which is processed through deep learning models such as LeNet-5 and Inception-V3. These models help reduce accidents by calculating optimal distances to obstacles, with the data shared through a mobile application to improve traffic efficiency [13]. Building on the integration of IoT and deep learning in traffic safety systems, addressing the challenges posed by adverse weather conditions on perception and sensing systems is crucial for enhancing reliability and accuracy. Weather can significantly affect sensor performance, but solutions like advanced sensor fusion, deep learning algorithms, and weather data integration offer promising improvements for Autonomous Driving Systems (ADS). Additionally, technologies such as V2X communication can enhance real-time awareness, enabling the detection of weather-related obstacles. Insights into the limitations of new LiDAR systems further contribute to overcoming these challenges, allowing for both basic warnings and advanced alerts that improve traffic safety and help prevent accidents [14].

As traditional emergency response systems often rely on centralized dispatching, which introduces delays in responder notifications and lacks real-time tracking. Additionally, many existing systems do not provide direct communication between emergency responders, driver, and hospitals. To address these limitation the study presents an IOT-based system that alerts drivers in real-time about nearby cars in low-visibility situations, such as dense fog, to improve traffic efficiency and vehicle safety. Data sharing through the app improves traffic flow, while integrated sensors reduce accidents by calculating optimal distances to obstacles. To increase the overall efficacy of emergency response operations, the system also incorporates a direct alert mechanism to notify the closest responder during emergencies and offers real-time updates and victim location information via a smartphone application. The remaining paper is presented as follows: the Section II presents the literature survey, Section III details the proposed architecture, Section IV is methodology, and algorithm, section V discusses the results and simulations, and the paper concludes in Section VI.

II. LITERATURE SURVEY AND ANALYSIS

This paper presents a survey of road traffic fatalities in Pakistan, highlighting the inefficiencies of convolutional methods in addressing traffic congestion. Rapid urbanization brought on by industrial expansion and rural-to-urban migration has made cities more crowded, making it more difficult to manage traffic effectively, especially when there is heavy fog. Pakistan's population has more than tripled over the past 50 years, primarily driven by high fertility and growth rates. Consequently, population density has increased from 60 people per square kilometer in 1961 to 308 people per square kilometer in 2024. Table I offers a summary of the population data since 1961. Pakistan conducted its 7^{th} population census, marking the largest digitization effort in South Asia [15].

TABLE I PAKISTAN'S POPULATION: SURVEY AND INSIGHTS

Year	Population (million)
1961	42.8
1972	65.3
1981	84.3
1998	132.4
2014	195.81
2017	207.7
2024	247.13

Despite recent advancements in road safety, road accidents remain a major global issue, causing 1.35 million deaths annually and nearly 50 million people suffer life-altering injuries each year. This ongoing issue is the 8th leading cause of death worldwide, road traffic accidents are predicted to rank as the seventh most common cause of fatalities globally by 2030 [16]. Every year, 20 to 50 million non-fatal injuries are caused by traffic accidents, which are the leading cause of fatalities among people aged 5 to 29. These injuries result in disability and financial losses. In most countries, road accidents result in economic losses equivalent to about 3% of GDP [17]. Road traffic accidents (RTAs) are influenced by several factors such as road conditions, driver irresponsibility, and environmental (weather, dense fog) variables [18]. Pre-hospital responsiveness, lack of airway management, and lack of cardiac resuscitation are factors associated with higher survival in EMS care. To increase survival rates, standardized EMS protocols for treating patients involved in traffic accidents must be developed [19]. Road traffic accidents are a significant global public health concern, causing 1.35 million deaths or disabilities annually, with 93% of road traffic injury related fatalities [20]. The situation is worsening in developing countries like Pakistan, where road fatalities continue to rise at an alarming rate. Road safety is a critical issue, causing health damage, economic losses, social suffering, and environmental harm [21]. From 2014 to 2023 Pakistan's road network registered vehicles and the population grew at a CAGR of 1.81% to 1.85%, during the same period, the number of road accidents increase of 1.5%. In 2023, a total of 10,971 road accident were reported by all region of Pakistan as shown in Table II [22].

TABLE II ROAD TRAFFIC ACCIDENTS AND FATALITIES IN PAKISTAN (2014–2023)

Year	Accident (Total)	No. of Fatal Accidents	No. of Persons Killed	No. of Persons Injured
2014	7865	3214 (3.33)	3954	9661
2015	9100	3591 (3.73)	4448	11544
2016	9582	4036 (4.2)	5047	12696
2017	11121	4829 (5.01)	5948	14489
2018	10779	4878 (5.06)	5932	13219
2019	9701	4403 (4.57)	5436	12317
2020	10429	4721 (4.9)	5816	12886
2021	10379	4566 (4.74)	5608	13059
2022	10617	4919(5.07)	5680	14722
2023	10971	5012(5.09)	5721	16432

The proportion of fatal accidents in total road accidents has steadily increased from 40.1% in 2014 to 47.3% in 2023, while the severity, measured by fatalities per 100 accidents, rose from

50.5 in 2012 to 58.03 in 2023.The severity of road accidents from 2012-2023 are illustrated in below in Fig. 1.

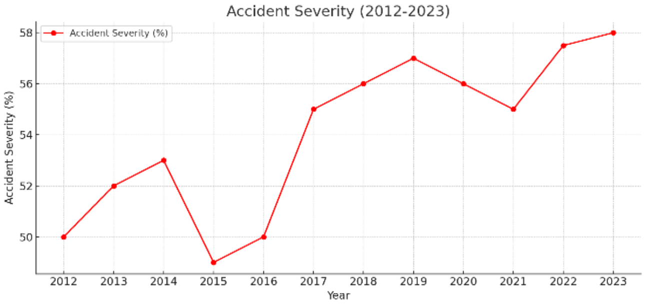


Fig. 1. Severity of road accidents.

Compared to 2020, there were 0.19 times as many traffic accidents in 2023. This indicates the overall number of traffic accidents has fallen slightly. However, compared to 2020, the number of fatalities caused by these traffic incidents rose by 1.013 times in 2023. This implies that the number of individuals seriously hurt in accidents may rise in a given year particularly as dense fog conditions remain a significant contributing factor to road accidents along with other environmental factors, significantly contribute to road accidents.

A. *Dense Fog Conditions and Environmental Impact*

Climate has a profound influence on human life however, low visibility condition such as fog, lead to low visibility, reducing drivers' ability to perceive and react to obstacles on the road while reducing situational awareness. This leads to an increased risk of accidents, as drivers may fail to detect slowing or stopping vehicles in time to respond appropriately [23]. Such environments often distort visual cues, further complicating navigation and increasing the likelihood of accidents, particularly in high-speed or congested traffic areas [24]. In both ahead and behind, thereby posing significant challenges to safe driving [25]. By employing advanced driving safety mechanisms, motorists can gain enhanced situational awareness of their surroundings [26]. Which emphasizes the need for effective warning systems and preventive measures to ensure road safety [27]. Due to the difficulty drivers face in detecting objects and vehicles in time to react appropriately especially under low visibility conditions, road accidents have become a serious concern in Pakistan, with the 2021 statistics which shown in Table III.

TABLE III COMPARISON OF ROAD ACCIDENT BETWEEN RURAL AND URBAN AREAS

Month	Rural Areas (%)	Urban Areas (%)
January	7.4	3.5
May	5.5	4.0
July	6.0	4.5
October	5.5	4.0

In 2021, road accidents in Pakistan as shown in Table III were more frequent during the month January, May, July, and October with 7.4, 5.5, 6.03 and 5.5 percent. The higher number of accidents in these months can be attributed to factors such as poor weather conditions and fog, which create hazardous driving environments. Additionally, rural areas accounted for 53.5% of the total accidents, with 63.4% of fatalities occurring in these areas, highlighting the greater risks in rural regions compared to urban areas. The most common times for traffic accidents were between 1500 to 1800 hours, (16.7%), 1800 to 2100 hours (16.6%), and 0000 to 0300 hours (6.3%) attributed to dense fog during those hours [28]. Human existence is impacted by climate change, as the ecology and air quality are impacted by growing industrialization and rising vehicle traffic. Due to decreased visibility, bad weather such as fog and haze plays a major role in traffic accidents. Fog which is known as mobile killer, significantly reduces visibility and makes driving difficult which increases the number of traffic accidents. According to statistics, accidents that occur on foggy days are 1.86 times more fatal than those that occur on clear days. In addition to impairing traffic safety, Fog also causes significant delays in transit on roads, trains and airports.

III. PROPOSED ARCHITECTURE

The proposed architecture integrates IoT sensors and a mobile application to enhance real-time monitoring, safety, and emergency response. It includes essential hardware and software components as shown in Table IV.

TABLE IV SIMULATION AND PROTOTYPE SPECIFICATIONS

Sr. No	Components	Description	
1	Arduino Uno	At mega 328p	
2	Buzzer / Alarm	5v	
3	LED Light	3.3 v	
4	WIFI Module	Esp. 8266	
5	Ultrasonic sensor	HC-SR05	
6	IMU Inertia Sensor	MPU 6050	
7	Arduino IDE	PL; C, C++, Java	
8	Proteus, Thinkercad	EDA Framework	

By lowering cloud-related latency and enhancing real-time data processing, fog computing improves IoT-based collision detection and warning systems. It improves public safety and disaster response by increasing emergency communication's efficacy, dependability, and affordability through the integration of mobile sensors and data decentralization at the network edge [29, 30]. This proposed study presents a cost-effective and user-friendly accident detection system and early warning system which utilizing the Blynk application, the system architecture is shown in below Fig. 2.

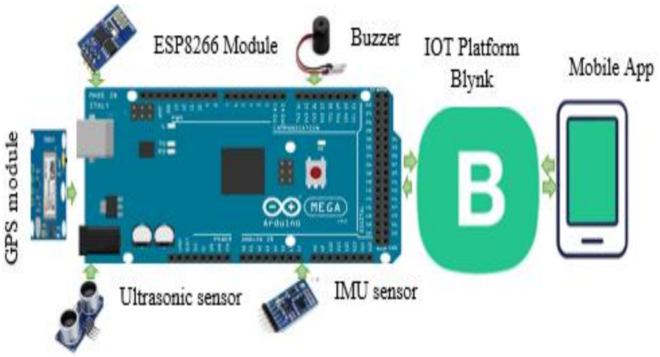


Fig. 2. The system architecture.

Blynk application provides real-time monitoring, control, real-time location, and alerts. This design demonstrates the versatility of Arduino hardware and Blynk as an intuitive human-machine interface (HMI), enabling efficient remote monitoring and control for modern automation applications. The key components included in this design are databases for effective data management and response, automated alerts, accident detection and early warning system.

A. *Early Warning System (EWS)*

Through sensor integration, the early warning system for collision detection continually monitors the distance between vehicles and surrounding objects to increase vehicle safety. The device reduces the possibility of crashes by sending out alerts when the front or back of the car gets near dangerously close distances from close obstacles.

B. *Accident Detection*

This module uses cutting-edge sensor technology to identify collisions and assess their severity. It gathers vital information about accidents, such as location and impact force, allowing for precise event identification, analysis, and action.

C. *Notification*

Once the accident is detected, an alarm will start for 30 seconds. Only information about local mechanics will be provided to the registered mobile, if the driver of the vehicle resets the alarm. Otherwise, the location is transmitted to the local police station and hospitals, if the alert is not reset.

D. *Databases*

To make operations more efficient, the proposed system uses a user details database, a vehicle database, a hospital database, and a police station database.

IV. METHODOLOGY

In everyday scenarios, accidents frequently occur due to various factors. The inability of vehicle operators to detect obstacles in front or behind significantly hinders their ability to prevent collisions, particularly in the absence of autonomous control systems [31]. By utilizes IoT sensors and cameras to gather real-time traffic data, which is processed using deep learning models and cloud computing [32]. It is a vital component of Intelligent Transportation Systems (ITS) by integration of IoT devices, sensors, cameras and related technologies facilitates the acquisition of real-time data on road and traffic conditions [33]. Which gathers, processes, and stores real-time road information, providing updates on traffic congestion and incidents via a roadside message unit. The system uses magnetic sensors and microcontrollers to process data, offering early warnings to improve traffic flow and save time [34]. And clustering algorithms performed on an Android device to processed data which shared with drivers' mobile application, providing real-time updates on traffic congestion and incidents through roadside messaging devices [35]. This enables real-time road condition monitoring, reducing accidents and fuel consumption, while providing drivers and commuters with access to real-time traffic updates via a using advanced technology [36]. To address the constraints of accident detection systems, this study offers an innovative approach to constructing a smart reporting and control system using Blynk application. Fig. 3 shows the block diagram for the IOT-based real-time collision detection system.

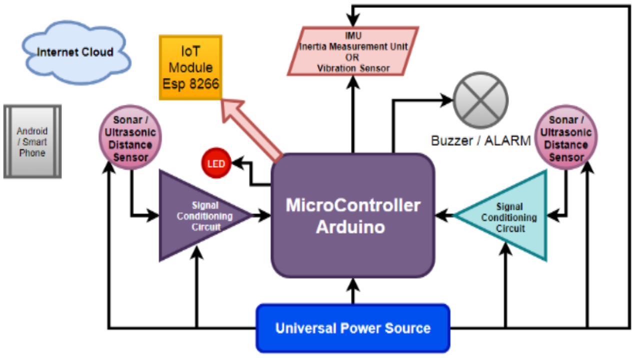


Fig. 3. Block diagram.

The approach uses the Blynk app to build a graphical user interface (GUI) for system control and real-time data collection. In contrast to traditional systems, this method integrates Arduino with the Blynk application without the need for specialized hardware, emphasizing simplicity and cost-effective.

The architecture of system follows a layered design, with each layer performing a distinct function as shown in Fig. 4.

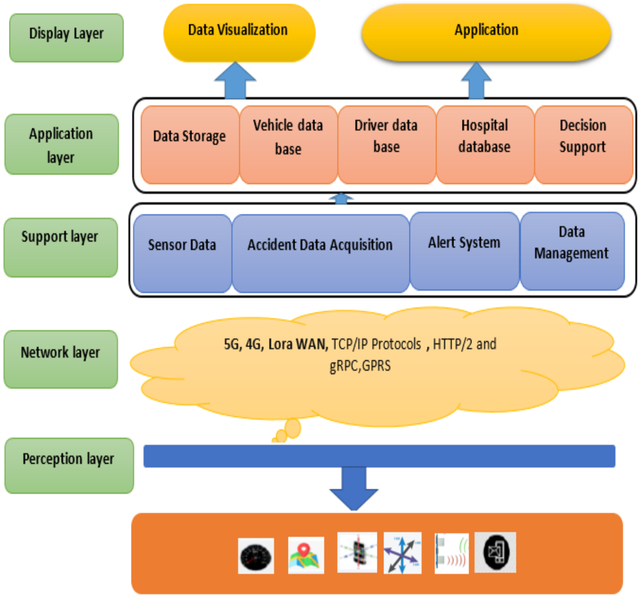


Fig. 4. Layered system architecture.

The system architecture consists of multiple layers, starting with the perception layer, which collects sensor data (speed, motion, and environmental parameters) using Arduino boards. This data is transmitted via the network layer, which bridges communication to the edge and cloud layers for processing and decision-making. The application layer stores critical information, while the application layer, powered by the Blynk app, provides a user interface for real-time monitoring, control, and notifications. This layered design demonstrates a robust, scalable and user-friendly automation system integrating IoT for efficient remote management.

The initial step involves establishing an interface between the microcontroller and the internet to enable smooth communication and data exchange. This connection forms the foundation for the system's functionality, ensuring real-time data transmission and processing capabilities. The algorithm detailing this process is outlined in Algorithm 1.

Algorithm 1: For internet interfacing of microcontroller

```
Input Data: Auth_Token, COM_Port
Output: Communication Status
Initialize
    Communication status ← ← 0
      Upload Blynk libraries to Arduino IDE.
        Generate Auth_Token in Blynk App and paste in serial USB
.          Blynk library file.
          Compile and run the program in Arduino IDE.
        Open `<<blynk-ser.sh` script and input COM_Port.
  If
        Arduino connects successfully ← ← 1
            communication status = 1:
          Play the Blynk App.
    else:
        Communication Status = Error.
  End
```

After successfully interfacing, the algorithm for sensor data acquisition and transmission to a remote location via the Internet outlines. The process for collecting sensor data and ensuring efficient real-time communication with remote systems. The detailed steps are presented in Algorithm 2.

Algorithm 2: For sensor data acquisition

```
Input: Sensor_Status
Output:  Notifications(1,0)
 Initialize
     Sensor_status ← ← 0
       Connect sensor to Arduino, Signal_Conditioning_Circuit.
            Calibrated_data ← Map  (Sensor_signal, Calibration).
          Add Calibrated_data to "Serial USB Blynk" library.
     Compile and upload the program to Arduino.
         Create GUI in Blynk app for user interaction and Run.
       If  data is displayed correctly: sensor_status ← ← 1
    If
         sensor_status = 1:
        Data_Acquisition_Status = Successful
   else:
         Data_Acquisition_Status = Error.
  End
```

After the successful execution of sensor interfacing and data acquisition. Fig. 5 illustrates the integration of hardware components, such as sensors and microcontrollers, with software systems. This combination ensures efficient data collection, processing, and transfer over the Internet, enabling smooth operation and reliable connectivity. The diagram also demonstrates how the application interfaces with the Internet cloud, ensuring real-time data synchronization. Furthermore, it highlights the connection between the Arduino and the sensors section, facilitating communication with the vehicle. The Blynk app GUI, developed in the Blynk app, enables users to receive notifications or alerts in the event of a collision or emergency, enhancing the system's responsiveness and user interaction. The architecture is a scalable solution, adaptable to various automation and IoT applications.

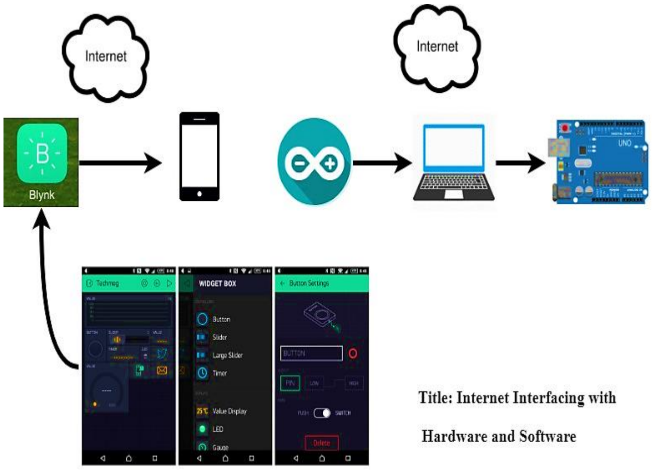


Fig. 5. Internet interfacing with hardware and software.

Building on the architecture explained, the system incorporates several features to improve efficiency and safety under varied circumstances. By using sensor data to deliver timely alerts, the early warning system enhances driver response and hazard detection. An IoT-based Android app and web server support real-time data processing and communication, allowing for smooth user system interaction. By maintaining appropriate vehicle distance, advanced techniques like distance estimate and calculation assist prevent accidents in difficult situations like dense fog. When combined, these elements guarantee a thorough strategy for preventing accidents, enhanced traffic control and monitoring.

A. Early Warning System

Early warning system enhances vehicle safety by using ultrasonic sensors to analyze distances and instantly identify potential accidents in real-time. It uses high frequency sound wave reflections to assess distance and operates on preset thresholds to provide audible and visual alerts to enhance situational awareness and prevent accidents. The distance d is calculated using the following equation [37].

$$d = V.\frac{t}{2} \tag{1}$$

Where v is the speed of sound and t is the time of flight, division of 2 accounting for the signal's round trip. The sensor emits a signal and measures the echo to calculate object distance, the threshold of 170 centimeters is set, and if the distance falls below this limit, it triggers an alert to warn the driver.

$$\text{A}=\begin{cases} if\ D < 170\ cm\ (Active\ alert) \\ if\ D > 170\ cm\ (No\ alert) \end{cases} \tag{2}$$

This threshold is designed to detect proximity risks that could result in an accident while reducing false alerts brought on by minute changes in distance. When the distance (d) falls below the threshold, the alarm mechanism is activated, triggering a flashing LED for visual warning and a buzzer for audible warning, represented by the alert function. The alert function A is represented as in Algorithm 3.

Algorithm 3: For alert mechanism

```
Input: Measured Distance (d)
Output:  Notifications ,  Alert collision status
 Initialize
       Collision_Alert ← 0
          Calculate the distance to the closest object.
        Measured_Distance  ← d
       Check if D is below the collision threshold:
    If
          d < 50:
        Collision_Alert ← 1
          Visual_Alert=Active
            Audible_Alert()=Active  // Trigger buzzer sound
          Notify_IoT_Network()= successful
         Send real time location and collision warning
   Else
          Collision_Alert ← 0
             Alerts ← "Deactive"
                Visual_Alert()= Deactivate
           Audible_Alert()= Deactivate
       Return Collision_Alert status:
  If
           Collision_Alert = 1:
          Status ← "Collision detection Alert Active"
   Else:
          Status ← "No Risk Detected"
  End.
```

B. *Iot Module for Detecting Accident*

Based on preset force and speed parameters, IOT module uses a force sensor on the car to identify collisions. A 30-second alarm is set off when an accident is detected. The driver can use a button to reset the alert if the event is small. If the system is not reset, it uses a GPS and an ESP8266 module to send an accident notification, which is shown on an LCD screen. For enhanced monitoring, vehicle information with location is also sent to a mobile device. An accident will happen if the values of force and speed are above a certain threshold, T_{speed} and T_{force} which is illustrated in Algorithm 4 [38].

Algorithm 4: For Accident Detection and response

```
Input: Speed(S) and Force(F)
Output: Accident_Status(AS)
         acc ← 0
  If (F > $T_{force}$ )AND S > $T_{speed}$ OR (F > $T_{force}$ OR S > $T_{speed}$):
           acc ← 1
  If acc = 1:
          Activate_Alarm (AT)
              AT ← 0
              Alarm_Timer ← Alarm_OFF ()
            If AT ≥ 30sec:
          Accident_Status ← "Accident Detected"
   else:
             Accident_Status ← "No Accident Accident"
                Notify_Owner ()
   If Accident_Status = "Detected":
          GPS_Location ← Get_Location ()
        Rescue_Operation (Nc)
           Hospital(x(t)
          Notify_Owner(v(t))
     End
```

The system utilizes ensemble transfer learning with dynamic weight adjustments to minimize false detections. To find the nearby hospital and police station, use the Haversine formula, which determines the shortest path between two points. The Haversine formula can be expressed as [39].

$$\text{Haversin } (\theta) = sin\text{\^{}}2\left(\frac{\theta}{2}\right) \tag{3}$$

Is an application of the Haversine formula, which is used to calculate the great-circle distance between two points on a sphere given their latitude (ϕ and longitude (γ).

$$\frac{d}{2} = haversine(\phi 2 - \phi 1) + cos(\phi 1) \cdot cos(\phi 2) \cdot haversine(\gamma 2 - \gamma 1) \tag{4}$$

Where d is equal to;

$$d = r \cdot hav^{-1}\left(\sqrt{h}\right) \tag{5}$$

By substitution equation 4 into equation 5 then we get.

$$d = 2r \cdot arcsin(\sqrt{} sin\text{\^{}}2(\phi 2 - \phi 1/2)\ + cos(\phi 1) \cdot cos(\phi 2) \cdot (\ sin\text{\^{}}2(2\gamma 2 - \gamma 1)\ \ /2) \tag{6}$$

Where d is the distance between the two points on the surface, r=6371 km and ϕ1, ϕ2 is earth radius, Latitudes of the two points. λ1, λ2: Longitudes of the two points γ, γ. This equation is used to calculate distances to nearby services and identifies the nearby facilities. It retrieves vehicle and service details, then sends a notification via GPS to relevant parties here is a flow chart of all procedures as shown in Fig. 6.

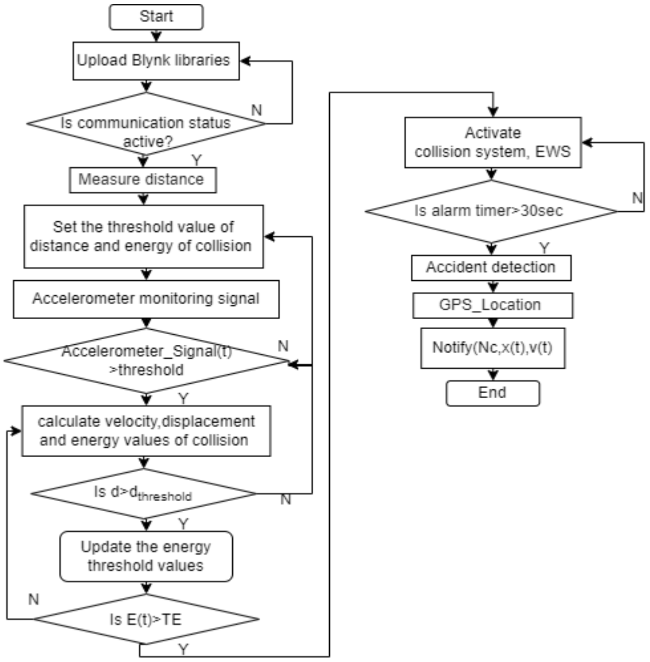


Fig. 6. Flow chart.

The flowchart illustrates a collision detection process using accelerometer data. Setting threshold values for variables like displacement and collision energy. The system continuously monitors accelerometer signals to check, if the acceleration exceeds the threshold, the system detect noise to improve detection accuracy including impact noises from accidents and then also check energy value. If it's not, the energy threshold values are updated by the system. Lastly, the collision system is triggered, indicating a possible collision, if the energy value is over the threshold. The velocity, displacement, and energy parameters utilized in the collision detection method are calculated using the following below formulas [40].

$$a(t)=Accelerometer\_Signal(t)$$

$$a = \frac{dv}{dt} \tag{7}$$

Where a is acceleration which is continuously monitored in the IoT system using accelerometer sensors. Sudden spikes in acceleration may indicate abnormal events like a collision.

$$v = \int a dt = \frac{dx}{dt} \tag{8}$$

Acceleration over time is integrated to calculate velocity (v), which gives information about vehicle speed. Abrupt deceleration is a key accident indication.

$$\mathrm{x} = \int v dt = \iint a dt dt \tag{9}$$

Where x is displacement, this parameter tracks the movement of the vehicle and helps assess whether it stopped or deviated significantly due to a collision.

$$J = \frac{da}{dt} \tag{10}$$

Where J is Jerk, high jerk values are often associated with collisions or sudden stops.

$$e = \int_{X0}^{X} a\, dx = \int_{v0}^{v} v\, dv = \frac{1}{2}(v^2 - v_0^2) \tag{11}$$

Sudden spike in energy density (e) suggests a potential collision which can represented as the following equation.

$$E = \frac{1}{2}m(v\text{^}2 - v_0^2) \tag{12}$$

The IoT system calculates the kinetic energy (E) of the vehicle using its mass and velocity.

$$v(t) = \int_0^t a(\tau)\, d\tau \tag{13}$$

Calculating distance (d) by integral of the velocity function.

$$d(t) = \int_0^t v(\tau) d\tau = \int_0^t (\int_0^t a(\eta) d\eta) d\tau \tag{14}$$

Power (E) represents the rate of energy transfer.

$$E(t) = \frac{1}{2}mv^2(t) \tag{15}$$

An IoT module tracks power to evaluate how quickly the vehicle's energy changes, for identifying abnormal scenarios.

$$If\ d(t) > d_{threshold}$$

It checks the threshold, if it satisfies this condition update energy threshold value and continue. And also check if;

$$a(t) > a_{threshold}(TA), d(t) > d_{threshold}(TD), (E(t) > E_{threshold}\,(TE)$$

Where TA is pre-set threshold for acceleration, TD is preset threshold for displacement and TE is pre-set threshold for energy and the collision system (A) define the system state:

$$Collision\_System(t)=A=1,0$$

$$A(t) = \begin{cases} 1; if\,(a(t) > a_{threshold}) \wedge (d(t) > d_{threshold}) \wedge (E(t) > E_{threshold} \\ 0; otherwise \end{cases} \tag{16}$$

As IoT sensors also detect noise to improve detection accuracy, including impact noises from accidents. The system can more accurately detect accidents and lower false alarms by integrating noise data from microphones or sensors.

$$N_c = N_{dB} \cdot f(SVP(t)) \tag{17}$$

Overall accident detection model is expressed as high-speed accident condition which is:

$$1\ if\ \left(a(t)\right) + \frac{N_{dB}}{140} + \frac{SVP(t)}{2.06} \geq T_A AND\ v(t) \geq T_S \tag{18}$$

And low-speed accident condition which is:

$$1\ if\ (a(t) + N_c) \geq T_A AND\ v(t) < T_S AND\ x(t) \geq TD \tag{19}$$

If above all conditions are staisfied then, check energy;

$$A(t) = \begin{cases} 1, if\ E(t) \geq TE\ \ (Accident\ Detected) \\ 0, otherwise\ (\ No\ Accident) \end{cases} \tag{20}$$

The system activates when the collision system (A) is equal to 1 only when all conditions are satisfied, 0 otherwise. When accident detected the system send notify service or emergency contacts of current location

$$\mathrm{Ambulance\_Route} = \mathrm{Find\_Path}(\mathrm{x(t)}, \mathrm{Hospital\_Location})$$

$$Notify(Nc, x(t), v(t))$$

$$If\ no\ confirmation\ within\ a\ set\ time\ (t_c)$$

$$False\_Alert = 1$$

The procedure is illustrated as in Fig. 7.

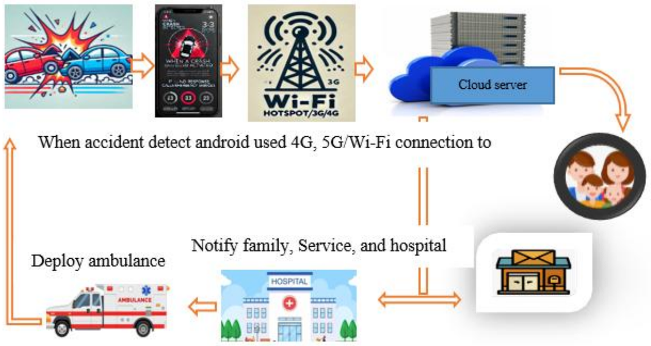


Fig. 7. Accident detection and emergency response system.

Using a smartphone's built-in sensors, GPS sensor, and accelerometer, the identification procedure aims to identify when an accident is occurred. These sensors are used in the proposed technique, which is depicted in the block diagram, for precise and effective automated accident detection. By integrating IoT technology, vital information regarding serious traffic accidents is sent to local police and hospitals, ensuring a timely and well-coordinated emergency response [41].

C. The Iot-based Android App and Web Server Design

After accident detection, the system promptly transmits data to android app or web server and sends SMS notifications to the victim's emergency contacts and relevant authorities [42]. And to determine the victim's location, including necessary details the system utilizes GPS, GSM, Wi-Fi module, MEMS sensors, and a microcontroller [43]. And a vibration sensor to detect collision impacts and a gyro sensor to monitor angular displacement. Upon detecting an accident, the system captures the vehicle's GPS coordinates and transmits them via GSM to emergency services and also alert displayed on mobile devices [44]. Additionally, users are prompted to input contact details for trusted individuals, who can be alert in case of an emergency. This demonstrates the potential for integration into vehicles to improve accident detection and reporting systems for faster medical and rescue responses. The focus of this work is to design software and development of the application, ensuring seamless integration with IoT hardware for accurate and reliable accident Monitoring and alert [45]. The proposed system is designed with Blynk integration, allowing users to register and log in to a mobile app that continuously monitors sensors, including the accelerometer and GPS for accident detection. Which is user-friendly interface for real-time data collection and monitoring which enabling efficient integration with IoT-based accident detection systems. Fig. 8 illustrates the complete process for developing an android-based IoT app that supports accident detection and notification.

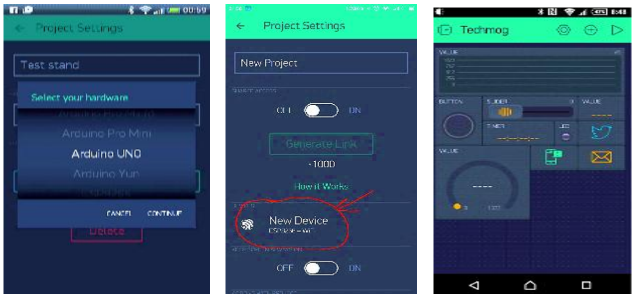


Fig. 8. Andriod application interfaces.

After completion of the above procedure, run the project by clicking on the run icon. The designed GUI will automatically run and data acquisition and control action can be achieved by this smart HMI.

D. Accident Prevention Technique in the Fog Environment

Fog diminishes visibility in outdoor pictures due to airflow absorption and light diffraction. Images shot outside are affected by a number of aspects, including dense fog, haze rain and adverse winter weather which result in reduced visibility. It made more difficult for drivers to detect other cars and obstacles, which has increased the number of traffic accidents. To overcome, this section provides a detailed description about the suggested system, integrated advance framework which uses subtractive blocks, adaptive multi-scale feature sharing, and contrastive regulation to Enhance image resolution, captures by front in real-time footage while driving in dense foggy weather, sends the frame to the image processor, which converts the foggy image to a defogging image. Dual streams manage multi-weather restoration, successfully reducing fogging and rain distortions [46]. Smart Road Safety and Vehicle Accident Prevention System (SRSP) integrates IoT, AI, and ML to improve road safety and preventing accidents. It utilizes a sensor network to collect real-time data, weather, and traffic density. Artificial intelligence models analyze this data to predict potential hazards and accident-prone areas by utilizing V2I and V2V communication for proactive safety measures, including smart speed regulation, hazard alerts, and automated emergency braking. In collision scenarios, the SRSP provides automatic notifications to drivers, nearby vehicles, and emergency services, enabling timely intervention as the process illustrated in below Fig. 9 [47].

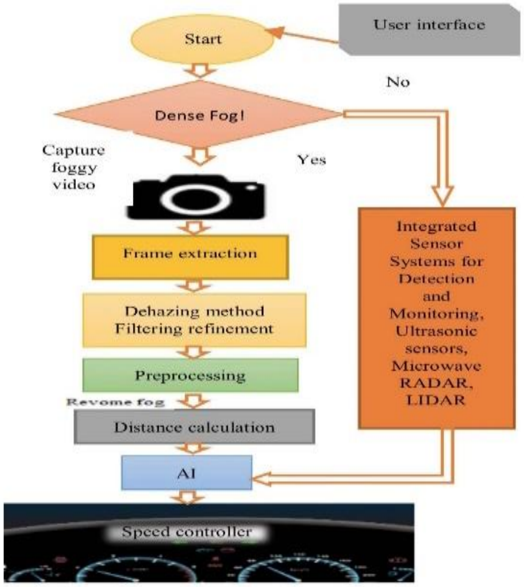


Fig. 9. Accident prevention technique in fog environment.

In order to improve efficiency and reliability in foggy weather conditions, the system utilizes the integration of edge computing and the Internet of Things. It presents a smart surveillance approach that reduces response times within intelligent transportation systems (ITS). While offering a comprehensive solution to mitigate the risks management, thereby saving lives, and diminishing the economic and preventing accidents. By utilizing an RFID-based system, incidents are quickly reported to the nearest field force, improving overall ITS efficiency [48]. And alert drivers to self-visual distraction when it occurs. Which utilized Convolutional Neural Networks (CNNs) to identify features and patterns indicative of erratic weather conditions [49]. The Proposed vehicular model improves upon the limitations of the intelligent driver model by embedding visibility factors to more accurately depict traffic patterns under adverse weather conditions, such as fog. In this model, vehicle acceleration is expressed as;

$$\frac{d_v}{d_t} = a_{max}\left(1 - \left(\frac{v}{v^0}\right)^{\delta} - \left(\frac{s^*}{H}\right)^2\right) \tag{21}$$

Where, a_{max} is the maximum acceleration, H is the distance headway and $s*$ is the desired distance headway which is given by [50].

$$s^* = s_j + Tv + \frac{v\Delta v}{2\sqrt{a_{max}a_{min}}} \tag{22}$$

A variable (δ) acceleration exponent is proposed to integrate driver reaction time, distance headway, and weather conditions for a more accurate representation.

$$\delta = \frac{T_r}{H}\left(\frac{V_d}{V_{d_{max}}}\right) \tag{23}$$

Visibility (V_d) represents the distance a driver can see during fog, with $V_{d_{max}}$as the maximum visibility [51]. The proposed model is developed by substituting Eq. (23) into Eq. (21).

$$\frac{d_v}{d_t} = a_{max}\left(1-\left(\frac{v}{v^0}\right)^{\frac{T_r}{H}\left(\frac{V_d}{V_{d_{max}}}\right)}-\left(\frac{s^*}{H}\right)^2\right) \tag{24}$$

The model incorporates visibility, providing a more accurate and realistic representation of traffic behavior compared to the ID model, Traffic flow adjusts to visibility depending on density and velocity, where density is the inverse of equilibrium headway by using the equation, which is q=ρv [52].

$$q = \frac{1}{H_e}v \tag{25}$$

Where H_e is;

$$H_e = (S_j + Tv)\left(1-\left(\frac{v}{v^0}\right)^{\delta}\right)^{-0.5} \tag{26}$$

Also

$$H_e = (S_j + Tv)\left(1-\left(\frac{v}{v^0}\right)^{\frac{T_r}{H}\left(\frac{V_d}{V_{d_{max}}}\right)}\right)^{-0.5} \tag{27}$$

Substituting, Eq. (26) and Eq. (27) in Eq. (25) gives the flow for the ID and proposed models as:

$$q = \frac{v}{(S_j+Tv)\left(1-\left(\frac{v}{v^0}\right)^{\delta}\right)^{-0.5}} \tag{28}$$

And

$$q = \frac{v}{(S_j+Tv)\left(1-\left(\frac{v}{v^0}\right)^{\frac{T_r}{H}\left(\frac{V_d}{V_{d_{max}}}\right)}\right)^{-0.5}} \tag{29}$$

This model provides a more precise representation of traffic flow (q) under various situations by taking into consideration velocity, visibility, and headway characteristics. For accurate forecasts, the model adjusts traffic flow to visibility, making it big in clear weather $V_d = V_{d_{max}}$ and small in foggy $V_d < V_{d_{max}}$. After completing all the processes images are sent to The AI engine, regulates the vehicle's speed, as illustrated in the schematic representation of the accident prevention technique for foggy environments in Fig. 9. In bad weather, timely obstacle detection depends on accurate distance estimation and calculation, to improving overall safety.

E. Distance Estimation and Calculation

Vehicles on the highway use equation (37), to determine the distance (d) between themselves and receiving GPS data from other cars by utilizing the equation (38). The side view includes camera height (h_c), the road normal vector (n), the ray vector to the measuring point (ψ), and the angle (α), which assist in calculating the distance (d) from the camera as shown in Fig. 10.

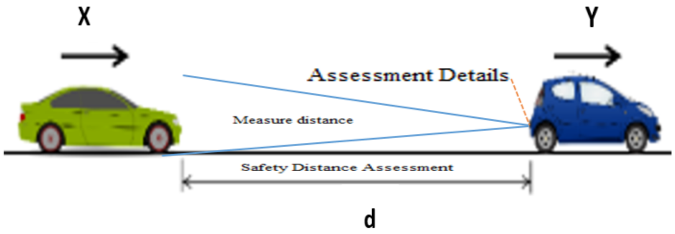


Fig. 10. Distance estimation process.

By using the image coordinates (x_p, y_p), the point can be reconstructed in homogeneous coordinates as:

$$Ph = \begin{bmatrix} x^p \\ y^p \\ 1 \end{bmatrix}^T \tag{30}$$

Using the following formula, determine the vector indicating the projection's direction from this location as;

$$\psi = k^{-1}.P_h \tag{31}$$

And camera height (h_c) and the road normal vector (n) [53].

$$n = k^T \cdot h_{hom} \tag{32}$$

Where,

$$h_{hom} = \left(\frac{\tilde{m}_h}{\tilde{b}_h} - \frac{1}{\tilde{b}_h}\ 1\right)^T \tag{33}$$

And using the back-projection ray (ψ) from the above equation, the distance (d) between the camera and the object can be calculated by applying right triangle geometry;

$$d = h_c tan\alpha \tag{34}$$

By simplifying the above equation 34.

$$d = h_c.\frac{sin\ \alpha}{cos\ \alpha} \tag{35}$$

As h_c is constant and |ψ| and |n| represent vector magnitudes.

$$d = h_c.\frac{|\psi|\cdot|n|\cdot sin\ \alpha}{|\psi|\cdot|n|\cdot cos\ \alpha} \tag{36}$$

So using the cross and dot product relation d is given by

$$d = h_c.\frac{|\psi \times n|}{\psi\cdot(-n)} \tag{37}$$

This method improves advanced driver assistance systems and encourages safer autonomous driving by providing accurate distance calculation. Distance estimation using GPS information of the other vehicles, the distance (d) between its vehicle as shown in below Fig. 11 and the other vehicles calculates the distance using the below Eq. (38).

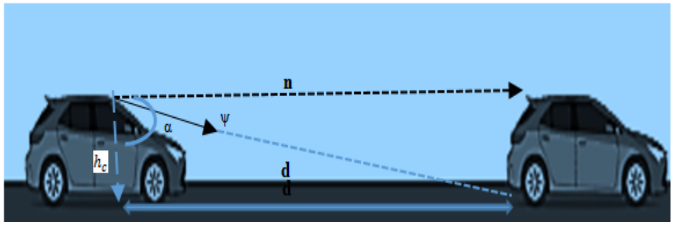


Fig. 11. Real-time vehicle safety distance.

Consider two cars, X and Y, in Fig. 11, where X is the one in front and Y is the one behind it moving faster than X.

Where,

lat_x, lon_x: *Latitude and longitude of Vehicle x*

lat_y, lon_y: *Latitude and longitude of Vehicle y*

$\Delta_{lat} = lat_y - lat_x$: *Difference in latitude*

$\Delta_{lon} = lon_y - lon_x$: *Difference in longitude*

To compute distance (d) [54].

$$d=R.C \tag{38}$$

Where R: Earth's radius (R=6371 km) and C is equal to;

$$C = 2 \cdot atan2\left(\sqrt{A}, \sqrt{1-A}\right) \tag{39}$$

And A is equal to;

$$A = sin^2\left(\frac{\Delta_{lat}}{2}\right) + cos(lat_a) \cdot cos(lat_b) \cdot sin^2\left(\frac{\Delta_{lon}}{2}\right) \tag{40}$$

After distance is calculated, to activate control measures for Vehicle x based on the threshold distance $d_{threshold}$ control;

If $d \leq d_{threshold}$, activate control system for Vehicle x

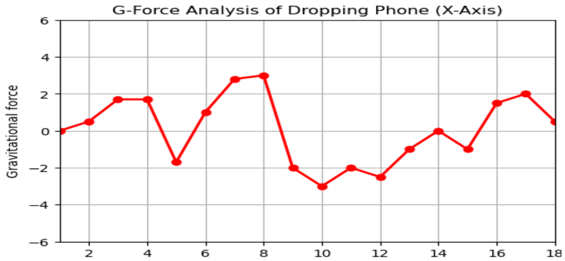
This ensures safe braking and speed reduction.

else If $d > d_{threshold}$, no control measures are activated

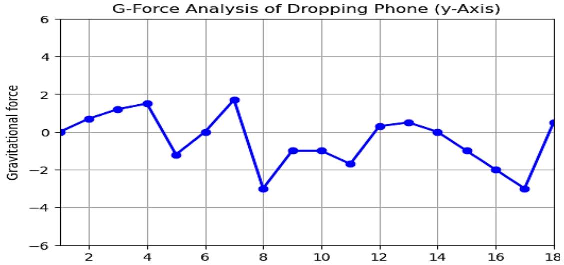
The AI engine uses calculated distance to prevent accidents, especially in adverse weather.

V. RESULTS

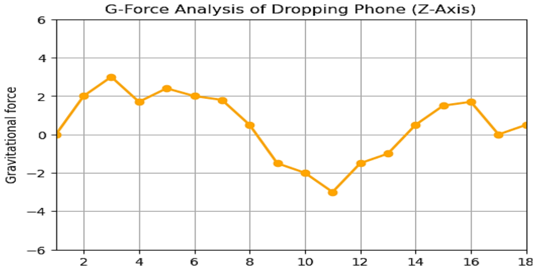
When victims are unable to ask for assistance after an accident, the advanced sensor integration increases the chance of saving lives by continually monitoring for traffic accidents and instantly sending emergency alerts to nearby rescuers. This solution secures and speeds up the alerting process by integrating all required components into a single system. During emergencies, the system assists in forwarding requests to the relevant emergency medical services (EMS) providers to help quickly manage emergencies by providing nearby incident details. Gravitational force values, speed, and pressure were evaluated under various driving circumstances to evaluate the threshold. The maximum G-force recorded was 3.1 G. These tests verify how well the Android app reacts to changes in the environment in real time as shown in below Fig. 12.



(a) Along the X-Axis



(b)Along the y-Axis



(c)Along the Z-Axis

Fig. 12. Values of G-force while dropping a smartphone (a, b, c).

We recorded the result of testing a smartphone by dropping it up to eighteen times. We found that an alarm is not set off by unintentional drops. However, if the g-force exceeds 4 g, the proposed system generates an alert.

A vibration sensor activates the collision detection system in the event of an accident, by providing visual feedback via a blinking LED and sound alarm. When the sensor detects abrupt changes in motion or impact force, the system is alerted to react instantly as shown in Fig. 13.

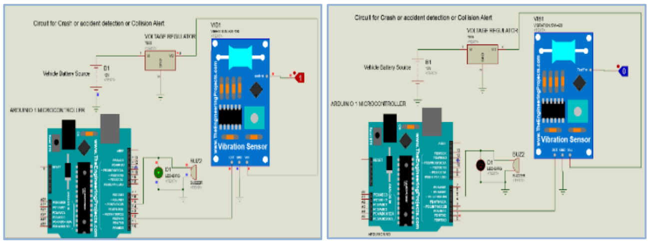


Fig. 13. Simulation of collision detection circuit.

The system can be further integrated with external modules to automatically send alerts or location data to emergency services for faster assistance. The graph demonstrates the output performance of the vibration sensor with time, sensor readings compared to an adjustable threshold level, as in Fig. 14.

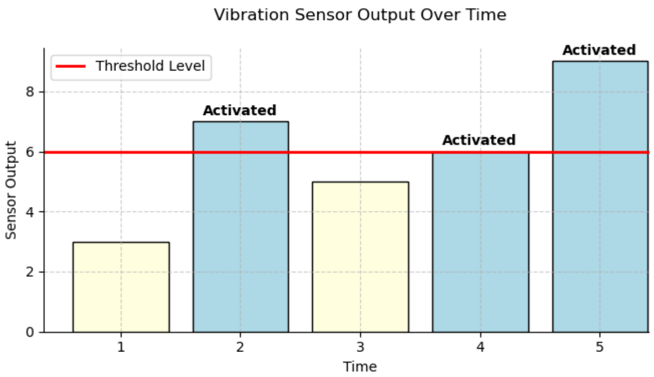
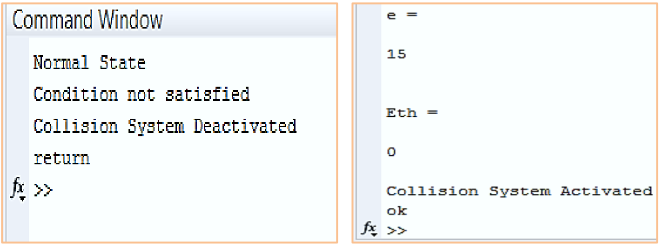


Fig. 14. Output performance of the vibration sensor.

To ensure validation, reliability, and accuracy of the proposed system, incorporating the design system into MATLAB software before implementation. Through this approach, the simulation process enables testing of the collision detection system under various scenarios and validates its capability to assess system performance. The performance in both normal and collision-activated scenarios is demonstrated by the simulation results as shown in Fig. 15.

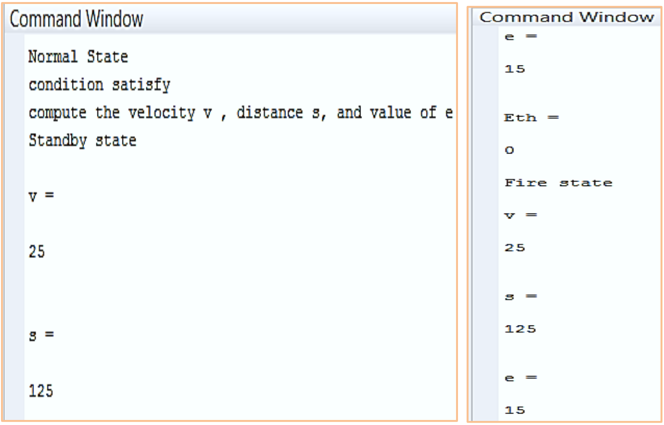


```
Normal State
Condition not satisfied
Collision System Deactivated
return
fx >>
```

```
e =

15

Eth =

0

Collision System Activated
ok
fx >>
```

Fig. 15. Simulation result using MATLAB.

These results validate the system's ability to monitor parameters and transition states based on energy thresholds.



```
Normal State
condition satisfy
compute the velocity v , distance s, and value of e
Standby state

v =

25

s =

125
```

```
e =

15

Eth =

0

Fire state

v =

25

s =

125

e =

15
```

Fig. 16. Simulation results using MATLAB tool.

The simulation results as in Fig. 15 and Fig. 16 indicate that the collision detection system controlled by the energy (e) and threshold (Eth) parameters. When the threshold energy (Eth) drops to zero during a fire, the system alters from a normal to a fire state and activates the collision mechanism.

The collision system uses an ultrasonic sensor to monitor the distance between vehicles, simulation shown in Fig. 17.

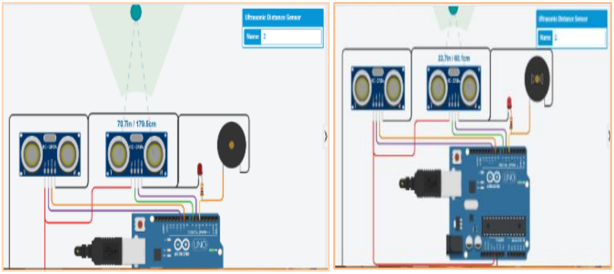
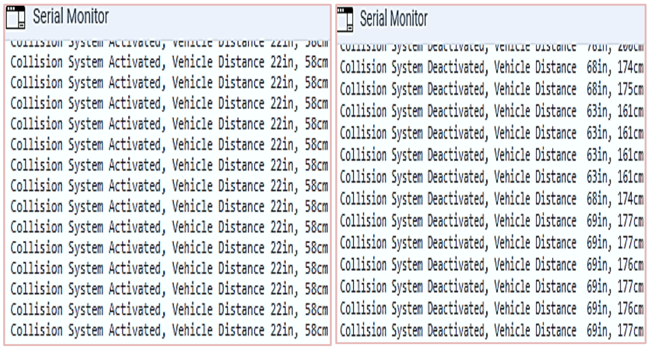


Fig. 17. Simulation of collision detection and warning system.

When a vehicle is detected at a distance of approximately 178cm, the system remains inactive, and no alarm is triggered which is illustrated in Fig. 18. However, when the distance reduces to 58 cm the system activates, signaling a potential collision scenario and triggering an alarm.



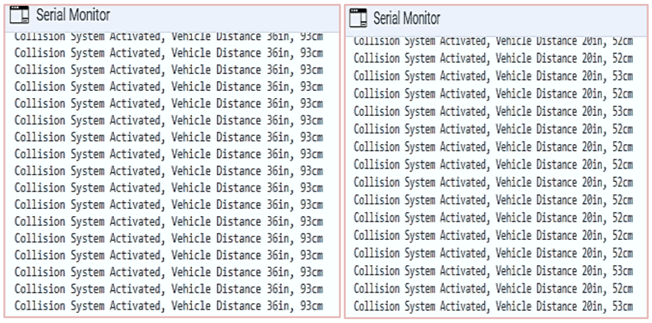
```
Collision System Activated, Vehicle Distance 22in, 58cm
Collision System Activated, Vehicle Distance 22in, 58cm
Collision System Activated, Vehicle Distance 22in, 58cm
Collision System Activated, Vehicle Distance 22in, 58cm
Collision System Activated, Vehicle Distance 22in, 58cm
Collision System Activated, Vehicle Distance 22in, 58cm
Collision System Activated, Vehicle Distance 22in, 58cm
Collision System Activated, Vehicle Distance 22in, 58cm
Collision System Activated, Vehicle Distance 22in, 58cm
Collision System Activated, Vehicle Distance 22in, 58cm
Collision System Activated, Vehicle Distance 22in, 58cm
Collision System Activated, Vehicle Distance 22in, 58cm
Collision System Activated, Vehicle Distance 22in, 58cm
Collision System Activated, Vehicle Distance 22in, 58cm
```

```
Collision System Deactivated, Vehicle Distance  68in, 174cm
Collision System Deactivated, Vehicle Distance  68in, 175cm
Collision System Deactivated, Vehicle Distance  63in, 161cm
Collision System Deactivated, Vehicle Distance  63in, 161cm
Collision System Deactivated, Vehicle Distance  63in, 161cm
Collision System Deactivated, Vehicle Distance  63in, 161cm
Collision System Deactivated, Vehicle Distance  68in, 174cm
Collision System Deactivated, Vehicle Distance  69in, 177cm
Collision System Deactivated, Vehicle Distance  69in, 177cm
Collision System Deactivated, Vehicle Distance  69in, 176cm
Collision System Deactivated, Vehicle Distance  69in, 177cm
Collision System Deactivated, Vehicle Distance  69in, 176cm
Collision System Deactivated, Vehicle Distance  69in, 177cm
```

Fig. 18. Vibration sensor serial output.

The results show that the collision detection system stays inactive at a safe distance of 174 cm and the system is active when the distance drops to 58 cm.

We carried out more tests to confirm the system's functionality. Fig. 19 shows the results of these tests, which demonstrate the system's ability to function reliably and efficiently in a variety of situations.



```
Collision System Activated, Vehicle Distance 36in, 93cm
Collision System Activated, Vehicle Distance 36in, 93cm
Collision System Activated, Vehicle Distance 36in, 93cm
Collision System Activated, Vehicle Distance 36in, 93cm
Collision System Activated, Vehicle Distance 36in, 93cm
Collision System Activated, Vehicle Distance 36in, 93cm
Collision System Activated, Vehicle Distance 36in, 93cm
Collision System Activated, Vehicle Distance 36in, 93cm
Collision System Activated, Vehicle Distance 36in, 93cm
Collision System Activated, Vehicle Distance 36in, 93cm
Collision System Activated, Vehicle Distance 36in, 93cm
Collision System Activated, Vehicle Distance 36in, 93cm
Collision System Activated, Vehicle Distance 36in, 93cm
Collision System Activated, Vehicle Distance 36in, 93cm
Collision System Activated, Vehicle Distance 36in, 93cm
Collision System Activated, Vehicle Distance 36in, 93cm
```

```
Collision System Activated, Vehicle Distance 20in, 52cm
Collision System Activated, Vehicle Distance 20in, 53cm
Collision System Activated, Vehicle Distance 20in, 52cm
Collision System Activated, Vehicle Distance 20in, 53cm
Collision System Activated, Vehicle Distance 20in, 52cm
Collision System Activated, Vehicle Distance 20in, 52cm
Collision System Activated, Vehicle Distance 20in, 52cm
Collision System Activated, Vehicle Distance 20in, 52cm
Collision System Activated, Vehicle Distance 20in, 52cm
Collision System Activated, Vehicle Distance 20in, 52cm
Collision System Activated, Vehicle Distance 20in, 52cm
Collision System Activated, Vehicle Distance 20in, 52cm
Collision System Activated, Vehicle Distance 20in, 53cm
Collision System Activated, Vehicle Distance 20in, 52cm
Collision System Activated, Vehicle Distance 20in, 53cm
```

Fig. 19. Output tested results on serial monitor.

These outcomes show that the collision system remains inactive at a safe distance but activates when a car enters the threshold distance, ensuring front and rear collision awareness and enhanced safety response measures.

The graph offers insights into system performance and operating patterns over time by providing an extensive visualization in real time that were captured throughout the monitoring process as shown in Fig. 20.

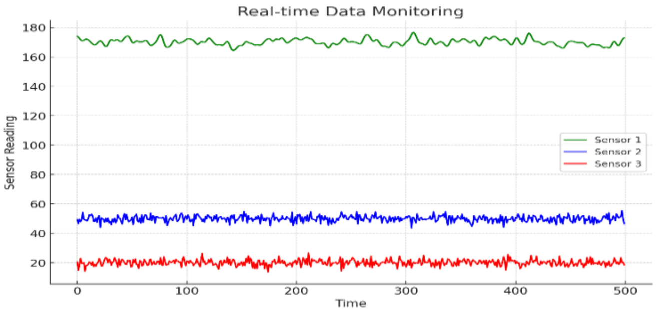
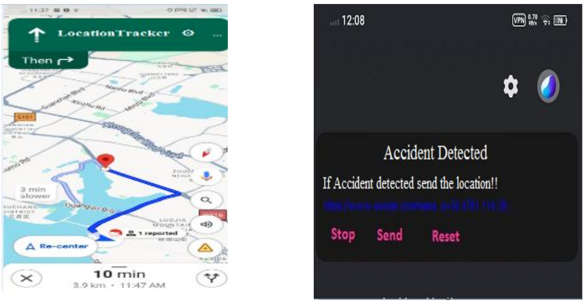


Fig. 20. Sensors data monitoring.

The accident detection system in operation is seen in Fig. 21 which shows the location tracking system giving real-time route direction to the accident scene, and smartphone alert notification of accident detection. This shows that the system detects risks and facilitates timely emergency action.



Accident Detected

If Accident detected send the location!!

Fig. 21. Real-time accident alert and ambulance interface.

The experimental setup intended for the automated identification of accidents is depicted in Fig. 22.

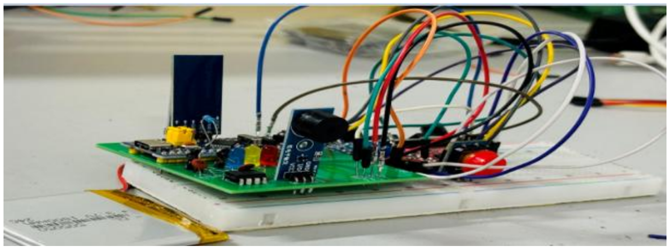


Fig. 22. Experimental setup.

The efficacy and performance of the collision system are displayed in two states in the graph below Fig. 23.

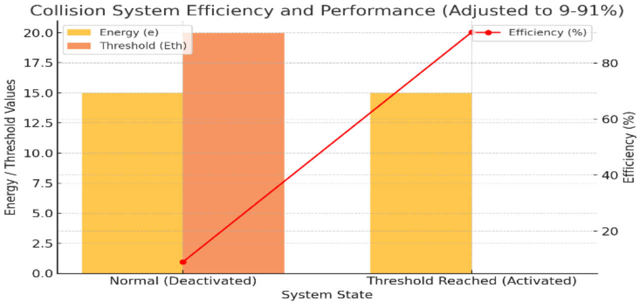


Fig. 23. System efficiency and threshold analysis.

The system activates with 91% efficiency at a zero threshold and remains inactive under normal conditions to prevent false alarm. The simulation results are shown in Fig. 24, which show that the system utilizes real-time data to identify incidents and initiate the proper reaction mechanisms.

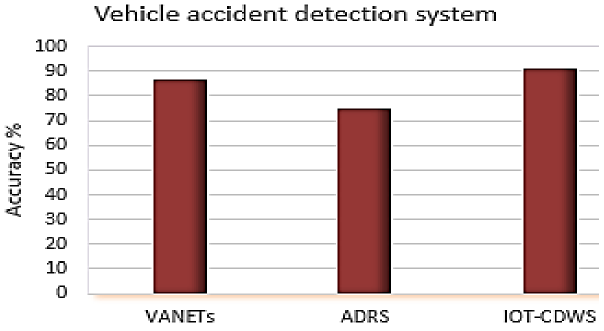


Fig. 24. Accident detection comparison.

The execution times of two current methods VNETs and ADRS with proposed IOT base system (IOT-CDWS), which consistently performs above the others in all eight combinations, illustrating an execution time savings of up to 17% as shown in Fig. 25.

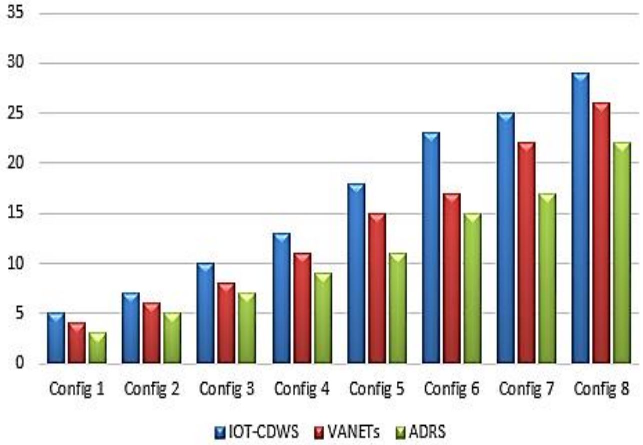


Fig. 25. Configuration compression.

When compared to VNETs and ADRS, the performance difference becomes more noticeable in higher configurations, indicating the effectiveness and scalability of the proposed approach in managing challenging demands.

VI. CONCLUSION

The proposed systems enable localized and reliable data processing, making them significantly valuable for IoT-driven real-time applications requiring immediate responses, such as accident detection and warning under low visibility conditions such as dense fog. It provides essential benefits, including low latency, regional information management, and enhanced traffic management capabilities, which are significant for reducing the risk of accidents and optimizing road safety in hazy conditions environments via real-time alerts based on distance calculation and obstacle detection systems. Compared to alternative system designs, the proposed model shows improvements in response time and execution speed, as accredited by test results. Their results were also endorsed through simulations and performance analysis using MATLAB software. In dense fog conditions, delays in emergency responses can significantly raise the risk of fatalities. This study proposes a solution utilizing IOT-based advanced technologies to detect collisions in real time, transmit critical data to nearby hospitals for quick response, and improve traffic flow. The system aims to minimize emergency delays, reduce accidents, early warning system, and enhance overall traffic safety management during adverse conditions. The proposed method lacks adaptive defogging in dense fog due to driver inattention and has limitations in pedestrian behavior prediction, affecting overall road safety. Future research can leverage Deep Reinforcement Learning (DRL) to enhance adaptive defogging, real-time driver assistance, and pedestrian behavior prediction. DRL can optimize visibility in dense fog, detect driver inattention, and predict pedestrian movements, improving overall road safety.

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