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Research Article

An IoT-Based Automatic Vehicle Accident Detection and Visual Situation Reporting System

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Road accidents are a major cause of injuries and deaths worldwide. Many accident victims lose their lives because of the late arrival of the emergency response team (ERT) at the accident site. Moreover, the ERT often lacks crucial visual information about the victims and the condition of the vehicles involved in the accident, leading to a less effective rescue operation. To address these challenges, a new Internet of Things (IoT)-based system is proposed that uses on-vehicle sensors to detect and report the accident to rescue operator without any human involvement. The sensor data are automatically transmitted to a remote server to create a visual representation of the accident vehicles (which existing systems lack), facilitating the situation-based rescue operation. The system tackles any false reporting issue and also sends alerts to the victim's family. A mobile application has also been developed for eyewitnesses to manually report the accident. The proposed system is evaluated in a simulated environment using a remote-controlled car. The results show that the system is robust and effective, automatically generating visuals of accident vehicles to facilitate informed rescue operation. The system has the potential to aid the ERT in providing timely first aid and, thus, saving human lives.

1. Introduction

In the 21st century, it is undeniable that human daily activities would not be possible without vehicles. On each coming day, more and more vehicles are on the roads [1, 2]. However, with this ever increasing number of vehicles, the likelihood of occurring road accidents is also rising exponentially, resulting in the loss of human lives [3–5]. According to the World Health Organization (WHO) report, nearly 1.3 million people die and 50 million people get injured in road traffic accidents each year [6–8]. Several efforts have been made to prevent accidents by analyzing road conditions [9], black ice on the road [10], vehicles and obstacles [11], prediction of threats to drivers for safe driving [12, 13], and evaluating them based on driving behavior [14]. Despite efforts, road traffic accidents are ranked as the eighth leading cause of death around the world and it may jump to the fifth rank in coming years. This situation is alarming, particularly for developing and underdeveloped countries which carry approximately 60% of the world's vehicles [15]. A high ratio of mortalities could have been prevented in developing and underdeveloped countries if medical care is provided in time as postaccidental 20 minutes are crucial [16] to save the injured people.

In developing countries like Pakistan, the provision of first aid to road accident victims is dependent on accident reporting to the emergency response team (ERT), usually by a third person. However, timely reporting of the accident is hindered by various factors, e.g., no eyewitness in the proximity, the exact location is unknown to the reporter, people feeling uncomfortable due to the inquires made by the ERT operator, fear of police involvement, eyewitness not having a phone (low penetration of cellular technology in low- and middle-income countries), and eyewitness having speech or hearing disability. In addition to this, people often cannot exactly describe the condition of the victims and the vehicles involved in the accident, preventing the situation-based rescue operation. Therefore, these challenges accelerate the need for an automatic accident detection and reporting system that offers accident scene visuals to facilitate well-informed rescue operation.

The IoT has emerged as a powerful technology that interconnects computing devices, enabling objects to send and receive data for day-to-day activities [17, 18]. In this study, we propose a novel IoT-based system that automatically detects road traffic accidents and subsequently informs both the emergency response service and the victim's family about the incident. The main contribution of this study is the generation of visual representation for the accident site that is lacking in existing studies, and the automation of accident reporting system that does not require human involvement. For this purpose, our system is based on various on-vehicle sensors controlled by ESP32 microcontroller unit (MCU) along with GSM service. When an accident occurs, the system automatically sends the exact location information and the sensor data to a remote server which creates a 3D visual scene of the vehicles involved in the accident, and sends a notification to the victim's family. The operator at the nearest emergency rescue center (ERC) receives the accident information along with visuals on his dashboard and takes necessary measures to initiate the situation-dependent rescue operation. The system also helps to prevent the false reporting issue by providing a report cancellation option to the vehicle driver. The system is coupled with a mobile application for bystanders, which is helpful if the sensors fail due to some reason. The proposed system provides a range of advantages, such as improved emergency response, increased road safety, useful data for analysis and decision-making, and simplified insurance procedures. In summary, we make the following key contributions:

(i) New system design: We design and develop a new IoT-based system that assists in reducing the human death rate resulting from vehicle accidents

(ii) Accident visuals creation: We propose a new approach as compared to state-of-the-art systems for the automatic rendering of accident visual scenes to assist a situation-specific rescue operation

(iii) Mobile application for accident eyewitness: Mobile application is developed for eyewitnesses to manually report the incident

(iv) Accident alerts: Automatic notifications are sent instantly to the ERC and the victim's family, even if the reporting module gets damaged, e.g., due to fire during an accident

This paper is organized into six sections. Section 2 overviews the related work followed by a proposed system in Section 3. Experimental analysis and results are presented in Section 4. Section 5 describes threats to validity of our study. Finally, Section 6 concludes with possible future directions.

2. Related Works

Road traffic accidents are rising day by day due to the large number of vehicles on the road. In this regard, Amin et al. [19] proposed a work that measures the vehicle speed by using GPS signals and requires someone to press the button to activate the accident reporting system. The work in [36] used sensors' values to apply machine learning (ML) algorithms at the node level for accident detection. The proposed model in [21] turns relays to trigger airbags, whereas the engine is turned off for drunk driver in [21, 28] for safety purposes. The studies in [29, 31] proposed an approach to use wearable medical sensors as well as to check the pulse rate, heartbeat, and muscle tension of the driver to infer the accident. All these studies use general packet radio service (GPRS) and/or short message service (SMS) to inform the emergency service about the time, location, and speed of the vehicle along with human involvement.

Nazir et al. [25] used sensors to detect the accident and alert drivers when an object is in 15–35 cm range from a vehicle. As an improved version of their work, Murshed et al. [30] included applying brakes and changing gear options when the vehicle is in the red zone. Khalil et al. [37] used two ultrasonic sensors at the front and back of the vehicle to detect a collision. Varma et al. [38] used infrared (IR) sensor to keep track of the distance between two vehicles and report the accident to the emergency service and the family. However, these elaborated methods have few limitations, e.g., IR sensor works on reflection principle and cannot detect dark color vehicles accurately, and also vehicle turnover cannot be perceived.

The roadside units and surveillance cameras are used in [39] to detect damaged cars by applying ML algorithms. The work in [40] applied multimodel deep learning to detect the accident, whereas the work in [41] also captured images from a distance to control road signals for ambulance. Chang at el. [42] proposed YOLO-CA, a deep learning model for accident detection. The convolutional neural network is used by authors in [43] to detect the accident and other anomalies in traffic. The work in [44] detected interaction between moving objects using YOLOv3 for crash, and it also determined trajectories for police report. However, all these studies have limitations, e.g., surveillance cameras are not installed everywhere as well as their accuracy is low, affected by weather conditions, and they are not applicable in general.

The researchers also used smartphone sensors to read the position, speed, noise, and pressure values and sent these data over the cloud to determine the accident [32]. The study in [33] used the same parameters as [32], but processing is performed on mobile edge for better response. The work in [7] used mobile application to send data to the nearest ERC for processing. Kumar et al. [34] proposed end-to-end IoT architecture to detect and classify accidents. However, smartphone availability and its sensor sensitivity are potential limitations and may also require proper positioning for accurate provisioning of data.

Yawovi et al. [27] used dashboard cameras installed in vehicles to take pictures of road signs and traffic signals to be processed using YOLOv3 and OpenCV to detect the accident and filling accident report template for insurance companies and police. The study in [45] is based on YOLOv5 and used mobile for edge computing, whereas the study in [35] used sensors along with a dashboard camera to send data to cloud for accident detection. However, these mentioned systems cannot report in real time. Moreover, they fail to detect the accident if the car has been hit from the back, in severe weather conditions such as dense fog, heavy rain, or situations with visibility issues.

Shubham et al. [46] reported that some vehicles like BMW have a built-in accident detection system. For instance, they used opening of airbags to detect and hereafter report the accident, but most of the vehicles do not have such prebuilt accident detection systems or airbags. Muthuswamy et al. [47] presented a survey paper explaining that how machine learning can optimize transportation routes, dynamically adjust delivery schedules, and even predict potential disruptions for sustainable supply chain management. Nabeeh [48] examined the environmental and economic aspects of sustainable road transport and highlighted the need to curb carbon emissions, boost energy efficiency, air cleaning, and easy access to transport. Sallam et al. [49] highlighted the importance of IoT in the supply chain management system. They also described the challenges, opportunities, and best practices.

The above literature highlights the fact that most of the studies do not provide optimal solution that work in majority of the conditions, and also no mechanism is provided to avoid false reporting. The prevention of false reporting can significantly reduce the burden on emergency teams as well as avoid undue stress to the family. However, the main contribution of our work is the introduction of the accident visual guide that is lacking in the previous studies and the automation of the accident reporting system that does not require human involvement once accident occurs. By summarising the literature survey (Table 1), it is concluded that dedicated multisensor-based system, supporting decision processes at the node level along with mobile application for reporting, is the best choice that is cost-effective and minimizes reporting delays.

3. Proposed System

This section explains the proposed system as shown in Figure 1. It is based on three major parts:

(i) Detection and reporting (DR) module: A hardware component comprised of IoT controller and sensors installed in the vehicle for automatic accident detection and reporting

(ii) Mobile application: It is used by pedestrians to report the accident

(iii) Rescue 1122 system: A central system that receives the accident report and acts accordingly

The detailed working of these three major components of the proposed system is presented below.

3.1. Detection and Reporting Module. This hardware module automatically detects accident and subsequently reports to Rescue 1122 headquarter and comprise of lilygo t-sim7000g esp32 (built-in GSM and GPS), ADXL345, and SW-420 sensors. It is installed in the vehicle and is powered from the vehicle battery. The module has dual reporting mode, it can report using GPRS, if the service is available, otherwise, it reports using GSM. This dual functionality is very helpful as GPRS service is often not available in remote areas. The Rescue 1122 server accepts the accident report from the DR module using GSM and Message Queue Telemetry Transport Protocol (MQTT) [50].

For integration, the DR module first needs to be registered with Rescue 1122 and assigned a registration number. The additional details are also saved on the rescue server against the module such as vehicle details, vehicle registration number, owner contact number, national citizenship number, owner residential address, and three contact numbers of victim's family. The user can modify some of the details such as emergency contact numbers by signing in through mobile application.

3.1.1. Accident Detection Process. In the detection process, the ESP32 controller determines the accident based on following three parameters:

(i) Acceleration

(ii) Angular movement of the vehicle

(iii) Vibration

Many studies show that axis values and speed changes when accident occurs [19–21]. Accident during car movement can affect speed, vibration, and may be the vehicle angle, whereas fall from the bridge affects all the 3 factors. Accident in the rest state can affect the angle and vibration.

(1) Acceleration. The vehicle speed is an important parameter to determine the accident. Any sudden change in the speed could be one of the accident's indicators. This change may be due to some collision or when brakes are applied. However, under normal condition when brakes are pressed, the change in speed is uniform. The work in [19] presents the maximum speed after deceleration when brakes are applied; we used these values to determine any abrupt change in speed possibly due to collision.

The vehicle speed is calculated using the GPS receiver. The DR module records the vehicle location twice a second using GPS to find the distance travelled. As the earth resembles a sphere, so we can use the Haversine formula to find distance d (in meters) between two points A and B on a sphere as follows:

$$d = 6378800 * \cos^{-1}\left(\sin(LatA) * \sin(LatB) + \cos(LatA) * \cos(LatB) * \cos(\mathrm{Long}B - \mathrm{Long}A)\right), \tag{1}$$

where latitude (Lat) and longitude (Long) values are in radians and 6,378800 is the radius of the earth in meters. As we are measuring distance twice a second ($t = 1/2$), and the equation for speed is ($v = d/t$), so vehicle speed in m/s can be found using the following equation:

Table 1: Research matrix summary.

	Real-time reporting	Avoid false reporting	Rollover detection	GPRS/GSM (dual mode)	Decision based on multiple sensors	Inform family	Report emergency service	Mobile app	Data processing	Protocols	Accident visuals
[19]	No	Yes	No	Yes	No	No	Yes	No	Node	—	No
[20]	Yes	No	No	No	No	Yes	No	No	Node	—	No
[21]	Yes	No	Not mentioned	No	No	Yes	Not mentioned	No	Node	—	No
[22]	Yes	No	Not mentioned	No	Yes	Yes	Yes	No	Node	—	No
[23]	Yes	No	No	No	No	No	Yes	No	Node	—	No
[24]	Yes	No	Not mentioned	No	No	Yes	Yes	No	Arduino as node	—	No
[25]	Yes	No	No	No	Yes	Yes	Not mentioned	No	Node	—	No
[26]	Yes	No	Not mentioned	No	Yes	Yes	No	No	Node	—	No
[27]	Yes	No	No	No	Yes	No	No	No	Node + server	Not mentioned	No
[28]	Yes	No	Not mentioned	No	No	Yes	Not mentioned	Yes	Node	—	No
[29]	Yes	No	Not mentioned	No	Yes	Yes	Yes	No	Node + server	Not mentioned	No
[30]	Yes	No	No	No	No	Yes	Not mentioned	No	Node	—	No
[31]	Yes	No	Yes	No	Yes	Yes	Not mentioned	No	Node + server	Not mentioned	No
[32]	Yes	No	No	No	Yes	Not mentioned	Yes	Yes	Cloud server	Not mentioned	No
[33]	Yes	No	No	No	Yes	Not mentioned	Yes	Yes	Smartphone as edge	—	No
[34]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Smartphone as edge	WebSockets (firebase)	No
[35]	Yes	No	Not mentioned	No	Yes	Not mentioned	Yes	Yes	Cloud	Not mentioned	No
[7]	Yes	Yes	Not mentioned	No	Yes	Yes	Yes	Yes	Fog	Not mentioned	No
[36]	Yes	Not mentioned	Yes	No	Yes	Not mentioned	Yes	No	Node	—	No
Our study	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Node + cloud	MQTT, REST	Yes

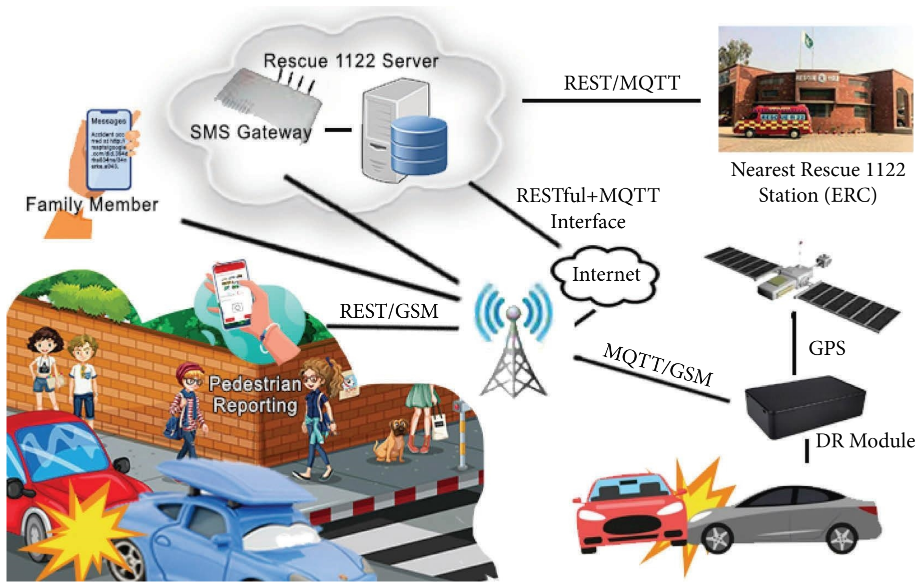

Figure 1: Proposed system design based on IoT devices.

$$v = 2 \times d. \quad (2)$$

The speed v is then compared against the final speed after one second as given in [19]. If the speed v is less than the threshold speed, then some external force (other than brakes) has acted on the vehicle. This change in speed is classified as abrupt otherwise as a smooth change.

(2) Angular Movement of the Vehicle. The sudden change in vehicle axis values can also be a sign of an alert. ADXL345 MEMS sensor senses the gravitational force acting upon x, y, and z axes of the vehicle. A circular buffer records vehicle motion every 1/5th of a second to maintain the record of the past 10 seconds of vehicle motion. When a vehicle is at rest, x and y axes have zero gravitational force while z axis carries a positive maximum gravitational force. By using gravitational force on the single axis, the angle can be measured as $\sin\theta = xb$ as shown in Figure 2, and for generality, if b is 1, the equation can be reduced to $\theta = \sin^{-1} x$, where x is the force acting on the x axis. As vehicle motion is translatory, the pitch can be measured between x and z values while the roll is measured between y and z axes (Figure 3).

The angle measurement using one or two axes of accelerometer results in lack of accuracy. Beyond $\pm 45^{\circ}$, sensitivity of a particular axis starts dropping off while sensitivity of another axis starts increasing. Therefore, more accurate angle can be measured by using three axes.

After scaling the output of accelerometer to ± 1 and by applying (3) and (4), which are derived in [51], the angle and pitch of the vehicle can be calculated, respectively. The pitch and roll represent the spatial position of the vehicle and are used to detect accident as shown in Table 2. These values also play a major role to generate visual scene. In this study, the notation y: $[0, 1]$ means the value of y starts from "0" and goes up to "1" and y: $[1, 0], [0, 1]$ means the value of y starts from "1" and drops to "0" and then it again goes up to "1."

$$\text{Pitch\_in\_degree} = \tan^{-1}\left[\frac{x}{\sqrt{y^2 + z^2}}\right] * \frac{180}{\pi}, \quad (3)$$

$$\text{Roll\_in\_degree} = \tan^{-1}\left[\frac{y}{\sqrt{x^2 + z^2}}\right] * \frac{180}{\pi}. \quad (4)$$

(3) Vibration. Vibration is another factor that helps along with other two parameters to detect the accident. When a collision occurs, it causes vibration in the vehicle. The vibration magnitude depends on the hit severity. The SW-420 sensor's vibration has been categorized into 3 levels, namely, low, moderate, and high [52] as given in Table 3.

3.1.2. Accident Reporting Process. After the DR module has detected an accident, it acts as an MQTT client to publish an accident report on a device-specific topic to rescue MQTT broker and triggers an alarm in the vehicle. The report is pooled on rescue server and temporarily marked as the initial report. It contains geographical coordinates, vehicle information, hit severity, speed of the vehicle, and the last 10 seconds 3D coordinates of the vehicle. The rescue server uses 3D spatial values to recreate the visual scene so that a situation-specific operation could be launched. The report is sent to Rescue 1122 over the GPRS using MQTT. If GPRS is not available in that vicinity, then it sends the same information in encoded form using SMS to rescue SMS gateway.

To avoid the false reporting, the DR module initially pools the reports on the server for a maximum period of 10 seconds. An alarm in the vehicle is used to deal with this situation. In case of false alarm, the driver must press the DR module reset alarm button within the time frame to discard the report on the server. As a result, a discard message is

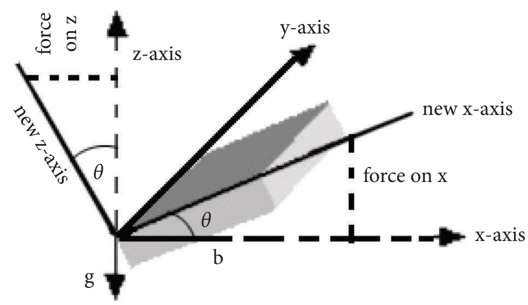

Figure 2: Gravitational force on axis.

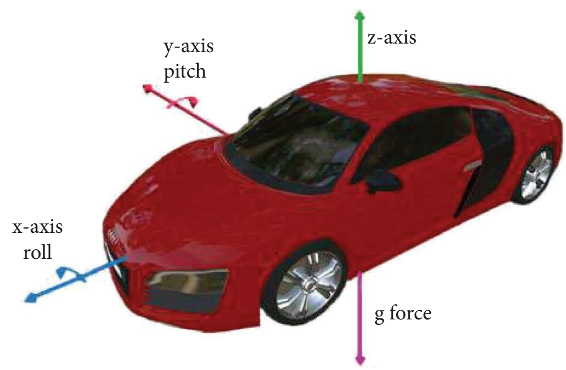

Figure 3: Vehicle pitch and rotation.

published on "device-specific report topic" or discard command is sent using SMS when broker is not reachable through GPRS. When the time window is over, the report is automatically confirmed and the rescue team can initiate its operation as shown in Figure 4. The server also sends a message about the accident to the listed family members.

3.2. Mobile Application. According to the statistics by Pakistan Telecommunication Authority (PTA), in February 2022, 87.17% of the population have cellphones and 50.67% of the population are 3G/4G subscribers [39]. Further, it has been found that 80% cellphone users have SMS packages as revealed in our survey. Hence, in view of the penetration of cellphones in our society, accident reporting system has been augmented with a mobile application (Figure 5).

The mobile application is particularly useful when victim's vehicle has no DR module installed. In this case, pedestrians can use the mobile application to report an accident to Rescue 1122. In addition to reporting, the application can be used by the vehicle owner to configure the DR module. This mobile application supports both SMS and GPRS. It can get all the necessary information in few taps, which is required by rescue personnel. The application needs location, SMS, Internet, and camera permissions. When the user installs the application for the first time, he/she needs to create the account. The account creation requires national citizenship number, cell number, and one-time password (OTP) to avoid fake accounts. Hence, every report made by a person is recorded against his/her citizenship number and they can be investigated later for any fake reporting. It can help to significantly reduce the fake reporting issue in the existing system. There are two ways to send the accident report: (i) using Internet services and (ii) SMS as explained below.

3.2.1. Report via Internet. This method is used to record and send the accident visual situation to Rescue 1122 personnel so that they could better understand the on-scene situation and launch the rescue operation accordingly. The reporting interface is shown in Figure 6. The user can select the vehicles involved in the accident and number of injured people and take up to 3 pictures or capture a short video of 10-second duration. This information along with the location coordinates (automatically obtained from the user's cellphone) is sent to Rescue 1122 by connecting to RESTful interfaces using GPRS. The report appears on the Rescue 1122 operator's dashboard in real time. After analyzing the situation, the operator initiates the appropriate rescue operation. Moreover, an acknowledgement notification is sent to the reporting person via the application.

3.2.2. Report via SMS. If the user does not have Internet facility, he can report the accident using in-app SMS option. However, this method does not provide visual situation to the rescue team and the rescue operator may call back for additional details. As before, the user selects the vehicle type and the number of injured people. The application automatically picks the user cellphone location and posts this

Table 2: Spatial position of vehicle based on 3D axis values.

Axis values	Interpretation	Vehicle status	Decision class
$x = 0$, $y = 0$, $z = 1$	Stable state or rotation around z-axis	Taking turn or moving steady	Normal
$x = 0$ y: [0, −1], [−1, 0] z: [1, 0], [0, −1]	Car rolling anticlockwise 0–90 and then 90–180°	Rollover, getting rolled towards left side, and going upside down	Smooth change up to 45° is normal; sudden change or >45° is abnormal
$x = 0$, $z = 0$, $y = -1$	Rolled at 90° anticlockwise	Hit from the right side or bump caused to roll on the left side	Abnormal
$x = 0$, $y = 0$, $z = -1$	Pitch changed/rolled at 180°	Car is upside down	Abnormal
$x = 0$ y: [0, 1], [1, 0] z: [−1, 0], [0, 1]	Car rolling anticlockwise 180 to 270°, 270 to 0°	Rollover, getting rolled towards the left side, and going downwards from upwards	Abnormal
$y = 0$ z: [1, 0] x: [0, 1]	Inclining path, getting on bridge. Pitch changing 0 to 90°	Car front side getting up, inclining bridge	Smooth change up to 45° is normal; sudden change or >45° is abnormal
$y = 0$, $z = 0$, $x = 1$	Car front side is straight up at 90°	Accident with solid blocking object	Abnormal
$y = 0$ z: [0, −1] x: [1, 0]	Rotation clockwise along pitch 90 to 180°	Car getting upside down by rotation along pitch	Abnormal
$y = 0$ z: [−1, 0] x: [0, −1]	Rotation of pitch 180 to 270°	Car getting downside up	Abnormal
$y = 0$ z: [0, 1] x: [−1, 0]	Pitch rotating clockwise 270 to 0°	Car is getting straight from front side down	Abnormal
x: [0, −1] $y = 0$ z: [1, 0]	Rotating pitch anticlockwise 0 to 90°	Car front side getting down, declining from the bridge	Smooth change up to −45° is normal; sudden change or <−45° is abnormal
$y = 0$, $z = 0$, $x = -1$	Pitch change to 90° anticlockwise	Car is front side straight down	Abnormal

Table 3: Vibration classes.

Vibration class	Sensor analog values	Details
Low	0–300	Vibration produced in moving vehicle or due to poor road condition (ignoreable)
Moderate	300–600	Low speed collision
High	600 and above	High speed hit

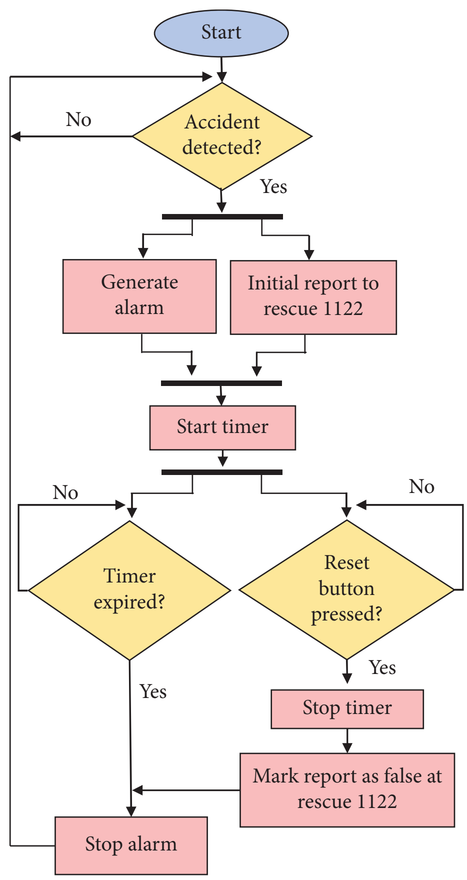

Figure 4: Accident detection and report pooling by module.

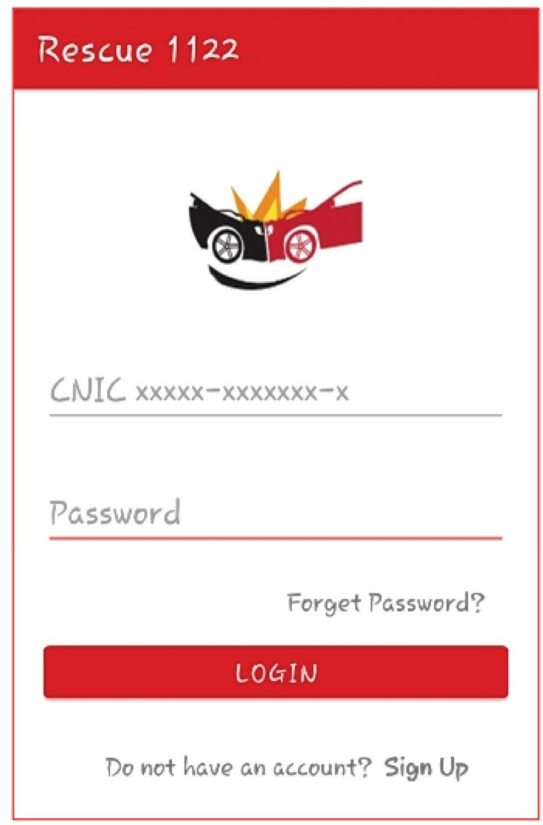

Figure 5: Mobile application login screen.

information to rescue in structured form through SMS. The GSM gateway at the rescue server receives the SMS and displays the accident information on operator's dashboard. The reporting person is also sent an acknowledgement SMS.

3.3. Rescue 1122 System. The Rescue 1122 system acts like IoT middleware that connects the DR module, mobile application, and ERC. This integration enables seamless communication and data exchange, ensuring that accident information from the DR module or from mobile application is efficiently relayed to the central ERC, facilitating swift and coordinated emergency responses [53]. This comprises of MQTT broker, RESTful API interfaces, and SMS gateway. The Rescue 1122 has multiple ERCs spread across the city. Each response center covers a specific geographical area. MQTT broker maintains response center-specific emergency topics, and the operator in response centers is subscribed to center-specific topic. When a report is received at broker, it segregates the received accident reports based on the location and publish it to center-specific emergency topic. Each report shows the variety of information including links to the profile of reporting person/DR module detail, accident site marker as a link to get pin-point location on Google map, and a button to view visual situation. The visual situation (video/image) may be sent by pedestrian using the mobile application. The rescue system can also automatically generate the visual scene of the last 10 seconds prior to accident based on values as sent by the DR module.

To generate the visual scene, models of different vehicles (car, van, coaster, bus, and truck) are designed in Unity 3D. The controllers are programmed in C# programming language that executes these models to show animated video to the operator. After receiving a report from the DR module, the rescue server automatically chooses a Unity 3D model matching the vehicle description and executes its controller. Upon execution, the controller connects to the API interface at the server to get the reported accident details (speed, 3D axis values, and vibration). The controller uses these values as input to execute the model. As a result, an animated scene of 10 seconds is generated to visualize the accident situation. The animation shows the speed of the vehicle and hit severity (vibration class). The animation also displays the final vehicle position based on the pitch and roll values.

Figure 6: Mobile application-report accident interface.

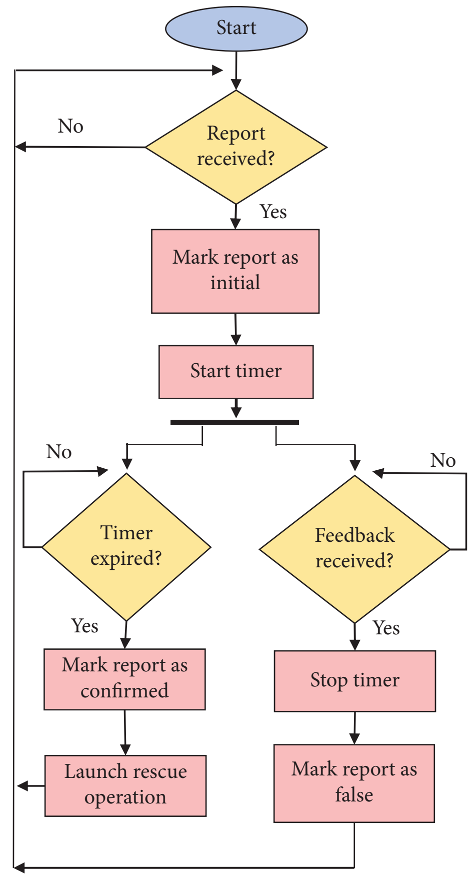

Figure 7: Report received from DR module at Rescue 1122.

Any report received from the DR module is categorized as the initial report upon reception and appears in the initial report section on the operator screen while reports received from the mobile application are categorized as confirmed. The initial reports are either dropped (if discard message is received from the driver) or assigned confirmed status automatically after 10 seconds (Figure 7). A report can be dropped only by the vehicle's driver by pressing a reset alarm button on the DR module if it was a false alarm. When the DR module generated report is confirmed, then the system sends an SMS to the victims' family on presaved numbers along with the incident location as a link to Google map. The rescue operation is launched only when a report is confirmed.

One important feature of the system is to detect duplicate reports. This situation may arise when more than one vehicle is involved in an accident, each having the DR module installed. It can also happen if the accident is reported by many witnesses simultaneously. The duplicate reports are filtered out by the rescue server using geofencing and time stamps. The system shows these reports as grouped entries to the operator (Figure 8).

4. Experimental Analysis

4.1. Experimental Setup. Considering the driver's safety, the cost of vehicles, and any damages to these, the proposed system is not tested in a real environment. However, the test environment is simulated using a remote-controlled (RC) car of 1/18 scale. For this purpose, the DR module comprised on sensors was installed in the RC car for accident detection and reporting. The DR module was powered using 5V battery. One ERC was created using core i5 with 4 GB RAM. The Rescue 1122 server is hosted on corei7 8 GB RAM, and the Unity 3D models, RESTful APIS, and IBM's RSMB MQTT broker used to maintain the ERC-specific topic. An extra GSM module was deployed on the server side to receive SMS. The ERC and Rescue server was connected using 8 Mbps Internet connection.

4.2. Results and Discussion. In this section, we discuss three different scenarios based on the sensor values obtained for car speed, pitch and roll, and vibration. We have used multiple sensors together to ensure the accuracy of accident detection. The sensors are calibrated first and the obtained data were processed and compared against the threshold values, using a decision table (Table 4) to detect any possible accident. The recorded values are sent to the server to publish the emergency to ERC and to generate the visuals.

4.2.1. Simulation for Bridge Crossing. When the vehicle crosses some bridge, its pitch changes. There may also be a minor change in roll on a banked bridge. The vibration sensor produces low vibration which is due to the steady movement of the vehicle and speed class is smooth. The movement of the vehicle along with x, y, and z axes is shown in Figure 9. The x axis varies smoothly indicating a change in

Figure 8: Rescue 1122 operator dashboard.

Table 4: Accident decision based on vibration, speed, pitch, and roll classes.

Vibration class	Speed class	Pitch and roll class	Accident detected?
Low	Smooth	Smooth	No
Low	Abrupt change	Smooth	No (quick break)
Low/moderate	Abrupt change	Change in roll or pitch up to $\pm$ 25°	No (bumpy road)
High	Abrupt change	—	Yes (a hit)
High	Smooth	Smooth	Yes (hit in rest state)
—	—	Abnormal	Yes (fall or severe rotation)

pitch. From points *a* to *b*, the movement of the vehicle is normal (zero pitch), and between points *b* and *c*, it starts ascending over the bridge (positive change in pitch), and after point *c*, the steep becomes low and the vehicle gets straight to the horizon (pitch becomes zero). After point *d*, the vehicle starts descending the bridge indicating a negative pitch. The decision table (Table 5) concludes no accident based on sensors' values.

4.2.2. Simulation for Accident due to Left Side Hit Causing Roll. This case may happen when the vehicle is at rest state with the driver inside and another high-speed vehicle hits it on the left side causing this vehicle to roll on its right side and finally it turns upside down. This case is simulated in Figure 10. The vibration sensor produces a high value upon hit and during roll while speed is zero (classified as smooth). From point *a* to *b*, the car is at rest state while at point *b*, an object hits the car on the left side causing it to roll. The *x* axis produces a minor variation while *y* and *z* axes exhibit drastic change. At point *c*, the car roll is changed to 90; the car fails to balance and continues rolling due to inertia. Hence, from points *c* to *d*, it rolled up to 180 . Using Table 6, we determine the roll and pitch class as abnormal. In Figure 11, we illustrate the system-generated visual scene of the situation at points *a*, *c*, and *d*.

4.2.3. Simulation for Accident due to Hit with Road Divider. Vehicles can hit the road divider due to many reasons such as negligence of the driver, overspeeding, or vehicle gets out of control. As shown in Figure 12, the *x* axis changes at once with a glitch while there is little change in *y* and *z* axes which hints changed pitch and roll. From point *a* to *b*, the vehicle is moving steadily while at point *b*, it gets out of control and hits with road divider. As a result, the vehicle's front side will be lifted up with slight bend on either side. The vibration sensor also produces a high value upon hit and speed class indicates an abrupt change as the vehicle comes to complete stop. The decision table (Table 7) indicates the accident occurred and rescue support is required.

The proposed system uses three different sensors to increase the accuracy of the accident detection process. Multiple tests of different scenarios are simulated as discussed above where the proposed system successfully detected all types of accidents. The proposed system eliminated any chances of false positives, a situation in which the system detects an accident but actually it did not happen. This scenario may occur due to the severe vibration as measured by the vibration sensor; however, the vibration may have been caused by the bumpy road or by some reason other than the vehicle-to-vehicle collision. The proposed system has the inherent capability to resolve this issue by providing an on-board button that the driver can press to cancel the accident detection report.

5. Threats to Validity

This study proposed an automatic system to detect and report road traffic accidents along with vehicle visuals to the ERC, in a timely manner. However, there are some

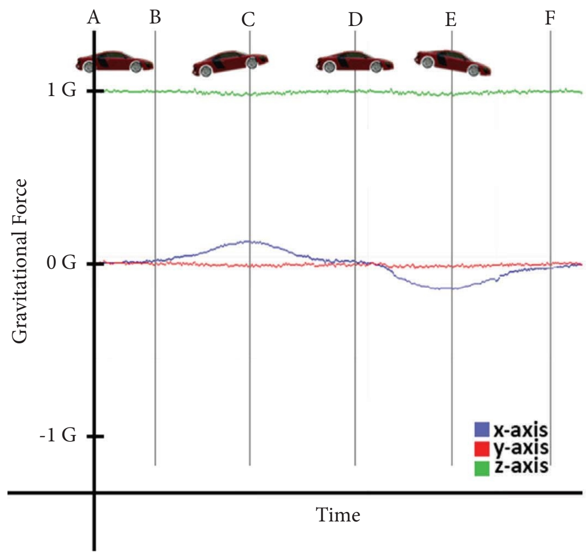

Figure 9: Gravitational force on vehicle during bridge crossing.

Table 5: Parameter values for no accident while crossing bridge.

Speed	Vibration	3D axis values	Decision
—(Smooth)	110–250 (low)	x-axis: [0, 0.25]; y-axis: [0, 0.02]; z-axis: [1, 0.95] (smooth change)	No accident

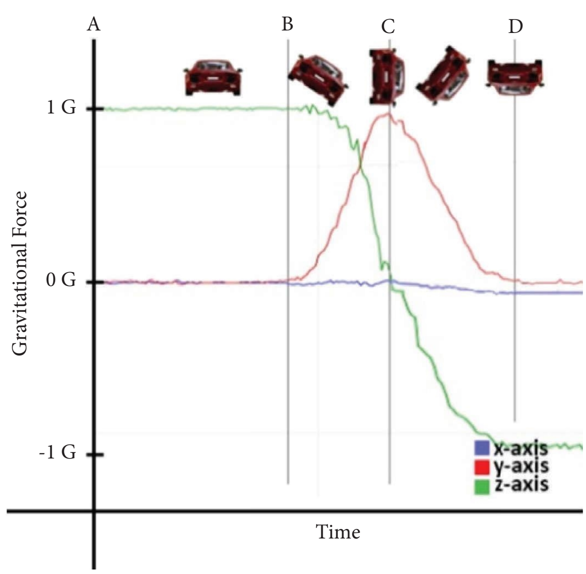

Figure 10: Car getting upside down due to clockwise rolling.

Table 6: Parameter values for clockwise rolling of vehicle.

Speed	Vibration	3D axis values	Decision
Zero (smooth)	630–783 (high)	x-axis: [0, −0.06]; y-axis: [0, 1] and [1, 0]; z-axis: [1, −1] (abnormal)	Accident occurred

limitations to this work. First, the proposed system needs to be evaluated in a real environment, particularly to determine if it can detect an accident under a speed lower than 15 km/h. In such situations, the vibration sensor may be of little help due to the negligible impact of the head-on-head collision. Second, rash driving/overspeeding on a bumpy road may indicate an alarming situation ringing accident bells. Third, MEMS sensors may require calibration. Fourth, vehicle rotation along the z-axis is not detected by our system; hence, the visuals of z axis rotation cannot be rendered. However, a Gyroscope sensor can be helpful to resolve this issue. The system is designed to work with all the road

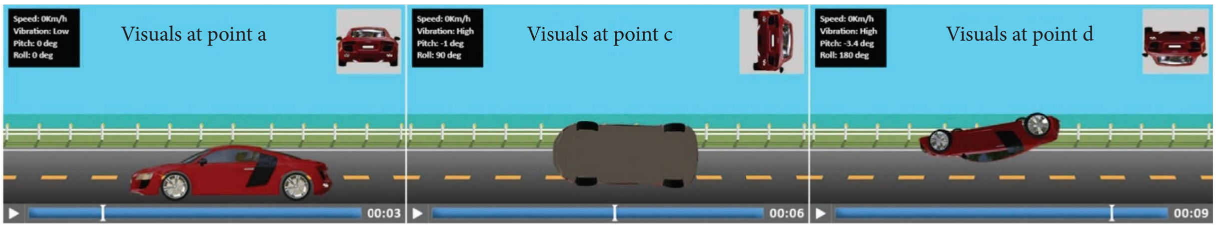

Figure 11: Visual scene for car getting upside down due to clockwise rolling.

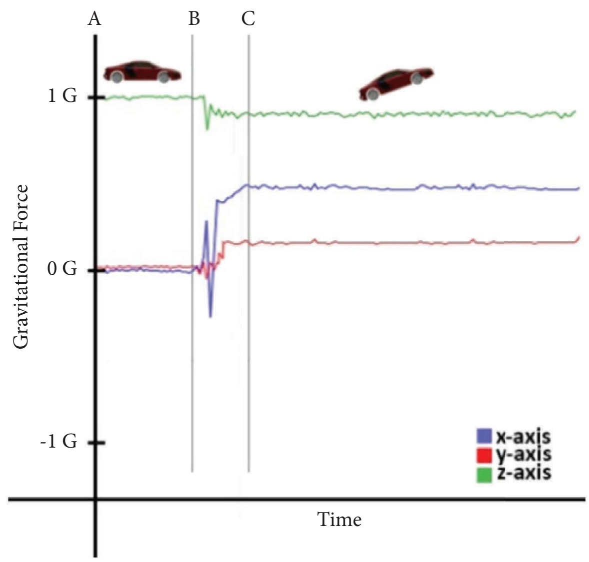

Figure 12: Vehicle hitting with road divider.

Table 7: Parameter values for vehicle hitting with road divider.

Speed	Vibration	3D axis values	Decision
10 km/h-0 km/h (abrupt change)	615–760 (high)	x-axis: [0, 0.5]; y-axis: [0, 0.18]; z-axis: [1, 0.91] (abnormal)	Accident occurred

conditions including rural areas where road patches are bumpy. These bad road conditions can raise vibration class to alarming situation, resulting in false reporting. To reduce the burden of false reporting on the ERC, the system sensitivity is kept medium, hence, it will not be able to report minor accidents. However, we have provided an explicit reporting mechanism through a push button.

6. Conclusion and Future Developments

The road traffic accidents are increasing rapidly and as a result, many people get injured or lose their lives. However, a significant number of human lives could be saved if injured people are rescued promptly. The rescue operation is often delayed, especially in developing and under-developed countries, as passersby are responsible for reporting the accident to the rescue team. However, people usually hesitate to call the rescue service because of being unfamiliar to the location, feeling uncomfortable due to rescue operator inquiries, fearing a police case, etc. Also, many times the rescue team lacks visual information about the accident victims and involved vehicles, leading to a less effective rescue operation. In this paper, a new IoT-based automatic vehicle accident detection and visual situation reporting system is proposed to address these challenges. The system successfully detects accidents, without third-party involvement, using on-vehicle sensors. The sensors' data are transmitted to a remote server, which automatically generates the visual representation of the vehicles involved in the accident which existing systems lack and notifies both the rescue operator and the victim's family. The system also has the inherent capability to prevent false reporting of the accident. A mobile application is also developed for passersby to manually report the accident with pictures or videos of the accident vehicles. The RC car is used to test the system and simulation results are found promising as the system successfully detected different accident scenarios. The system has the potential to save many valuable lives by timely reporting the accident to the rescue team and subsequently facilitating in-time medical care.

In future, the system will be extended to identify hotspots along the road where accidents occur frequently. The hotspot information will be shared, in advance, with all nearby vehicles to avoid accidents.

Data Availability

The data used to support the findings of this study are available from the corresponding authors on request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Shahzad Aslam contributed in design and development of this study. Shahid Islam worked on the proposed methodology. Natasha Nigar and Sunday Adeola Ajagbe analyzed the results and wrote the original draft, whereas Matthew O. Adigun reviewed the article.

References

[1] Y. R. B. Al-Mayouf, O. A. Mahdi, N. A. Taha, N. F. Abdullah, S. Khan, and M. Alam, "Accident management system based on vehicular network for an intelligent transportation system in urban environments," *Journal of Advanced Transportation*, vol. 2018, no. 1, Article ID 6168981, 11 pages, 2018.

[2] A. Azhar, S. Rubab, M. M. Khan et al., "Detection and prediction of traffic accidents using deep learning techniques," *Cluster Computing*, vol. 26, no. 1, pp. 477–493, 2023.

[3] H. M. Ali and Z. S. Alwan, "Car accident detection and notification system using smartphone," *International Journal of Computer Science and Mobile Computing*, vol. 4, pp. 620–635, 2015.

[4] U. K. Singh, S. Yadav, S. Joshi, S. Singh, and K. Jayavel, "RescueAlert-an accident detection and rescue mechanism," *International Journal of Electrical and Computer Engineering*, vol. 11, no. 4, p. 3356, 2021.

[5] Z. A. Almusaylim, N. Zaman, and L. T. Jung, "Proposing a data privacy aware protocol for roadside accident video reporting service using 5G in Vehicular Cloud Networks Environment," in *Proceedings of the 2018 4th International conference on computer and information sciences (ICCOINS)*, pp. 1–5, IEEE, Kuala Lumpur, Malaysia, August 2018.

[6] Organization Wh, "Global status report on road safety 2018," 2022, https://apps.who.int/iris/rest/bitstreams/1164010/retrieve.

[7] B. K. Dar, M. A. Shah, S. U. Islam, C. Maple, S. Mussadiq, and S. Khan, "Delay-aware accident detection and response system using fog computing," *IEEE Access*, vol. 7, pp. 70975–70985, 2019.

[8] D. Tian, C. Zhang, X. Duan, and X. Wang, "An automatic car accident detection method based on cooperative vehicle infrastructure systems," *IEEE Access*, vol. 7, pp. 127453–127463, 2019.

[9] R. Madli, S. Hebbar, P. Pattar, and V. Golla, "Automatic detection and notification of potholes and humps on roads to aid drivers," *IEEE Sensors Journal*, vol. 15, no. 8, pp. 4313–4318, 2015.

[10] H. Lee, M. Kang, J. Song, and K. Hwang, "The detection of black ice accidents for preventative automated vehicles using convolutional neural networks," *Electronics*, vol. 9, no. 12, p. 2178, 2020.

[11] T. Alsuwian, R. B. Saeed, and A. A. Amin, "Autonomous vehicle with emergency braking algorithm based on multi-sensor fusion and super twisting speed controller," *Applied Sciences*, vol. 12, no. 17, p. 8458, 2022.

[12] A. Tota, L. Dimauro, F. Velardocchia, G. Paciullo, and M. Velardocchia, "An intelligent predictive algorithm for the anti-rollover prevention of heavy vehicles for off-road applications," *Machines*, vol. 10, no. 10, p. 835, 2022.

[13] A. Kashevnik, A. Ponomarev, N. Shilov, and A. Chechulin, "In-vehicle situation monitoring for potential threats detection based on smartphone sensors," *Sensors*, vol. 20, no. 18, p. 5049, 2020.

[14] A. Kashevnik, I. Lashkov, and A. Gurtov, "Methodology and mobile application for driver behavior analysis and accident prevention," *IEEE Transactions on Intelligent Transportation Systems*, vol. 21, no. 6, pp. 2427–2436, 2020.

[15] A. org, "Road crash statistics," 2022, https://www.asirt.org/safe-travel/road-safety-facts/.

[16] J. Lee and H. Lee, in *Platinum-Time Operation Measures to Reduce Traffic Fatalities*, Modern Environmental Science and Engineering, Gerais, BR, USA, 2018.

[17] S. A. Ajagbe, M. O. Adigun, J. B. Awotunde, J. B. Oladosu, and Y. J. Oguns, "Internet of things enabled convolutional neural networks: applications, techniques, challenges, and prospects," *IoT-enabled Convolutional Neural Networks: Techniques and Applications*, pp. 27–63, 2023.

[18] D. Han, H. Zhou, T. H. Weng et al., "LMCA: a lightweight anomaly network traffic detection model integrating adjusted mobilenet and coordinate attention mechanism for IoT," *Telecommunication Systems*, vol. 84, no. 4, pp. 549–564, 2023.

[19] M. S. Amin, J. Jalil, and M. B. I. Reaz, "Accident detection and reporting system using GPS, GPRS and GSM technology," in *Proceedings of the 2012 International Conference on Informatics, Electronics & Vision (ICIEV)*, pp. 640–643, IEEE, Dhaka, Bangladesh, May 2012.

[20] J. M. Iqbal and S. H. Kousar, "Automatic vehicle accident detection and reporting with black box," *International Journal of Applied Engineering Research*, vol. 10, no. 87, pp. 139–145, 2015.

[21] A. R. Wakure, A. R. Patkar, M. V. Dagale, and P. P. Solanki, "Vehicle accident detection and reporting system using GPS and GSM," *International Journal of Engineering Research and Development*, vol. 10, no. 4, pp. 25–28, 2014.

[22] G. K. Grewal and M. Lochan, "Vehicle collision detection and reporting," *International Journal of Innovative Research in Technology*, vol. 5, no. 4, 2018.

[23] M. K. Angrula and M. N. Kaur, "Car accident detection and reporting system," *International Journal of Innovative Research in Technology*, vol. 6, no. 12, pp. 229–232, 2019.

[24] L. Vijayaraja, R. Dhanasekar, R. Magesh Krishna, M. Mahidhar, D. Prakash, and P. Shashikumar, "A low cost and user friendly vehicle crash alert system using arduino," in *IOP Conference Series: Materials Science and Engineering*, vol. 1055, no. 1, p. 012061, IOP Publishing, Bristol, UK, 2021.

[25] R. Nazir, A. Tariq, S. Murawwat, and S. Rabbani, "Accident prevention and reporting system using GSM (SIM 900D) and GPS (NMEA 0183)," *International Journal of Communications Network and System Sciences*, vol. 7, no. 8, pp. 286–293, 2014.

[26] K. Singh, M. Narpareddi, S. Bhalekar, and S. Inamdar, "An IOT based accident reporting and tracking system," *International Journal of Innovative Research In Technology*, vol. 6, no. 12, pp. 794–798, 2020.

[27] A. H. Yawovi, T. Ozono, and T. Shintani, "Implementing an automatic and instant road accident report system using Knowledge System," *FIT*, vol. 2, pp. 353-354, 2019.

[28] D. Selvathi, P. Pavithra, and T. Preethi, "Intelligent transportation system for accident prevention and detection," in

Proceedings of the 2017 International Conference on Intelligent Computing and Control Systems (ICICCS), pp. 442–446, IEEE, Madurai, India, June 2017.

[29] S. Sharma and S. Sebastian, "IoT based car accident detection and notification algorithm for general road accidents," *International Journal of Electrical and Computer Engineering*, vol. 9, no. 5, p. 4020, 2019.

[30] M. Murshed and M. S. Chowdhury, "An IoT based car accident prevention and detection system with smart brake control," in *Proceedings of the International Conference on Applications and Techniques in Information Science (iCATIS)*, vol. 23, Manipal, India, December 2019.

[31] K. A. Khaliq, A. Qayyum, and J. Pannek, "Prototype of automatic accident detection and management in vehicular environment using VANET and IoT," in *Proceedings of the 2017 11th International Conference on Software, Knowledge, Information Management and Applications (SKIMA)*, pp. 1–7, IEEE, Malabe, Sri Lanka, December 2017.

[32] F. Bhatti, M. A. Shah, C. Maple, and S. U. Islam, "A novel internet of things-enabled accident detection and reporting system for smart city environments," *Sensors*, vol. 19, no. 9, p. 2071, 2019.

[33] M. H. Alkinani, A. A. Almazroi, N. Jhanjhi, and N. A. Khan, "5G and IoT based reporting and accident detection (RAD) system to deliver first aid box using unmanned aerial vehicle," *Sensors*, vol. 21, no. 20, p. 6905, 2021.

[34] N. Kumar, D. Acharya, and D. Lohani, "An IoT-based vehicle accident detection and classification system using sensor fusion," *IEEE Internet of Things Journal*, vol. 8, no. 2, pp. 869–880, 2021.

[35] W. J. Chang, L. B. Chen, and K. Y. Su, "DeepCrash: a deep learning-based Internet of vehicles system for head-on and single-vehicle accident detection with emergency notification," *IEEE Access*, vol. 7, pp. 148163–148175, 2019.

[36] M. Balfaqih, S. A. Alharbi, M. Alzain, F. Alqurashi, and S. Almilad, "An accident detection and classification system using internet of things and machine learning towards smart city," *Sustainability*, vol. 14, no. 1, p. 210, 2021.

[37] U. Khalil, T. Javid, and A. Nasir, "Automatic road accident detection techniques: a brief survey," in *Proceedings of the 2017 International Symposium on Wireless Systems and Networks (ISWSN)*, pp. 1–6, IEEE, Lahore, Pakistan, November 2017.

[38] S. K. C. Varma and P. T. V. Harsha, "Automatic vehicle accident detection and messaging system using GPS and GSM modems," *International Journal of Scientific Engineering and Research*, vol. 4, no. 8, p. 1937, 2013.

[39] V. Ravindran, L. Viswanathan, and S. Rangaswamy, "A novel approach to automatic road-accident detection using machine vision techniques," *International Journal of Advanced Computer Science and Applications*, vol. 7, no. 11, 2016.

[40] D. Singh and C. K. Mohan, "Deep spatio-temporal representation for detection of road accidents using stacked autoencoder," *IEEE Transactions on Intelligent Transportation Systems*, vol. 20, no. 3, pp. 879–887, 2019.

[41] V. C. Maha Vishnu, M. Rajalakshmi, and R. Nedunchezhian, "Intelligent traffic video surveillance and accident detection system with dynamic traffic signal control," *Cluster Computing*, vol. 21, no. 1, pp. 135–147, 2018.

[42] D. Tian, C. Zhang, X. Duan, and X. Wang, "An automatic car accident detection method based on cooperative vehicle infrastructure systems," *IEEE Access*, vol. 7, pp. 127453–127463, 2019.

[43] S. W. Khan, Q. Hafeez, M. I. Khalid et al., "Anomaly detection in traffic surveillance videos using deep learning," *Sensors*, vol. 22, no. 17, p. 6563, 2022.

[44] Y. Sui, S. Zhou, Z. Ju, and H. Zhang, "A vision-based system design and implementation for accident detection and analysis via traffic surveillance video," *IEEE Canadian Journal of Electrical and Computer Engineering*, vol. 45, no. 2, pp. 171–181, 2022.

[45] Z. Xia, J. Gong, H. Yu, W. Ren, and J. Wang, "Research on urban traffic incident detection based on vehicle cameras," *Future Internet*, vol. 14, no. 8, p. 227, 2022.

[46] S. P. Shubham, M. Kumar, and S. Jain, "A survey on IoT based automatic road accident detection," in *Proceedings of the 2021 5th International Conference on Intelligent Computing and Control Systems (ICICCS)*, pp. 1–7, IEEE, Madurai, India, May 2021.

[47] M. Muthuswamy and A. M Ali, "Sustainable supply chain management in the age of machine intelligence: addressing challenges, capitalizing on opportunities, and shaping the future landscape," *Sustainable Machine Intelligence Journal*, vol. 3, 2023.

[48] N. Nabeeh, "Assessment and contrast the sustainable growth of various road transport systems using intelligent neutrosophic multi-criteria decision-making model," *Sustainable Machine Intelligence Journal*, vol. 2, 2023.

[49] K. Sallam, M. Mohamed, and A. Wagdy Mohamed, "Internet of things (IoT) in supply chain management: challenges, opportunities, and best practices," *Sustainable Machine Intelligence Journal*, vol. 2, 2023.

[50] Mqtt org, "MQTT specification," 2022, https://mqtt.org/mqtt-specification/.

[51] C. J. Fisher, "Using an accelerometer for inclination sensing. AN-1057, Application note," *Analog Devices*, pp. 1–8, 2010.

[52] I. E. A. Pakpahan, P. Sihombing, and M. K. Nasution, "Analysis of the sw-420 vibration sensor performance on vibration tools by using a fuzzy logic method," in *Proceedings of the International Conference on Culture Heritage, Education, Sustainable Tourism, and Innovation Technologies (CESIT 2020)*, pp. 543–550, Medan, Indonesia, January 2020.

[53] O. Source, "Rescue 1122," https://www.rescue.gov.pk/.