

A Network Resilient Vehicular Black Box for Automatic Accident Detection and Direct Medical Alerting.

Mr. K Boopesh¹, Dr. M Sindhu², Mr. R Sasikumar³, Mr. M.Nandha kumar⁴

^{1,3,4} Department of Mechanical Engineering, ² Department of Mathematics,

^{1,2} Knowledge Institute of Technology Salem TN- India, ³ Gnanamani College of Engineering, Namakkal TN- India, ⁴ Excel Engineering College, Komarapalayam TN- India.

Boopesh k – boopeshnidhu2005@gmail.com, Dr. M Sindhu – msindhu0387@gmail.com,
Mr. R Sasikumar – sasikumarr.india@gmail.com, Mr. M.Nandha kumar – nandhajfk@gmail.com

ABSTRACT :

Road traffic accidents continue to be a major cause of fatality worldwide, particularly in remote regions such as hilly areas, forests, rural highways, and during night time travel. In many cases, loss of life occurs not only due to the severity of injuries but also because emergency medical assistance fails to reach the accident location within the critical golden hour. Existing accident reporting mechanisms rely heavily on human intervention, mobile phones, or continuous network availability, which often become unreliable when victims are unconscious or network coverage is poor. This paper presents an automatic accident detection and emergency alert black box system designed to operate autonomously without user interaction. The proposed system is permanently installed in vehicles and continuously monitors vehicle dynamics using embedded sensors. Upon detecting a severe crash, the system automatically generates an emergency alert containing real time location and crash severity information. The alert is transmitted directly to nearby hospitals and ambulance services using adaptive communication methods, ensuring reliable operation even in low connectivity or network absent environments. Unlike conventional systems, the proposed solution is vehicle independent, compatible with multiple vehicle types, and equipped with an internal backup power supply to ensure functionality after power failure. In addition to emergency notification, the system performs continuous data logging for post accident analysis, similar to an aviation black box. Performance evaluation shows a significant reduction in accident detection time and rescue response delay, thereby improving survival probability. The proposed system offers strong potential for enhancing road safety infrastructure and saving lives in high risk and remote travel conditions.

Keywords: Accident detection, emergency alert system, vehicular black box, road safety, GPS tracking, intelligent transportation systems.

1. LITERATURE REVIEW :

[1] Routh et al. (2019) proposed an automatic vehicle accident detection and messaging system using GPS and GSM modules. Their work focused on threshold based crash detection and alert transmission to predefined contacts, highlighting the need for automated accident reporting.

[2] Jadhav et al. (2025) developed a smart car accident detection and emergency alert system with real time GPS location sharing. The system improved response awareness but was dependent on continuous mobile network availability.

- [3] **Deeksha et al. (2025)** introduced a lightweight vehicle black box system capable of storing crash data and sending emergency alerts. Their work emphasized post accident data analysis but did not address communication reliability in remote regions.
- [4] **Siam et al. (2024)** presented a real time accident detection framework for two wheelers using physiological signal monitoring and motion sensors. The approach enhanced rider safety but relied on wearable devices and continuous data transmission.
- [5] **Ingle and Mapari (2020)** proposed a real time accident detection and tracking system using GPS and GSM technology. Their study improved location accuracy but required uninterrupted vehicle power and network connectivity.
- [6] **Talukder et al. (2022)** explored vehicle collision detection and prevention using VANET based IoT and vehicle to vehicle communication. Their research primarily focused on collision avoidance rather than post accident emergency response.
- [7] **Satish and Karuna Sagar (2025)** developed a mobile based accident detection and emergency notification system. Although cost effective, the system depended on smartphone availability and user configuration.
- [8] **Dangat et al. (2022)** implemented a GSM and GPS based embedded accident detection system. The system demonstrated practical feasibility but lacked backup power support after severe crashes.
- [9] **Pujari (2024)** presented an accident alerting system using GPS and GSM with predefined emergency contacts. Direct integration with hospitals or ambulance services was not considered.
- [10] **Aravind et al. (2018)** proposed a vehicle black box system with SMS alert functionality. Their work focused on recording vehicle parameters and sending alerts but lacked autonomous emergency routing.
- [11] **Kaul et al. (2020)** designed an accident alert and vehicle tracking system aimed at fleet monitoring. The system emphasized vehicle tracking over medical emergency response.
- [12] **European Commission (2019)** standardized the eCall automatic emergency calling system for vehicles. While effective in urban environments, the system relies on centralized emergency call centers and cellular networks.
- [13] **National Highway Traffic Safety Administration (2020)** discussed event data recorders used for post crash analysis. These systems record accident data but do not provide real time emergency alerts.
- [14] **International Organization for Standardization (2009)** defined standards for automatic emergency call systems in intelligent transportation systems, providing a regulatory framework for vehicular emergency communication.
- [15] **Adewopo et al. (2022)** reviewed accident detection techniques for smart transportation systems, highlighting sensor based and vision based approaches for automated crash identification.
- [16] **Kumar et al. (2018)** developed an accident detection and alerting system using GPS and GSM technology. Their work demonstrated low cost implementation but remained dependent on mobile network connectivity.
- [17] **Bhat and Kulkarni (2019)** proposed a smart accident detection and notification system using Raspberry Pi and sensor integration. The system required external power and lacked redundancy mechanisms.
- [18] **Manjesh and Raj (2014)** introduced a smart helmet system using GSM and GPS for accident detection in two wheelers. The approach improved rider safety but relied on helmet usage compliance.
- [19] **Rani et al. (2017)** developed an intelligent accident detection and alerting system focusing on automated emergency message generation. The system did not address network failure scenarios.
- [20] **Al Fuqaha et al. (2015)** provided a comprehensive survey on Internet of Things technologies, which laid the foundation for connected vehicular safety and monitoring systems.
- [21] **Cheng et al. (2020)** investigated intelligent vehicle collision detection and warning systems using vehicle to vehicle communication, emphasizing accident prevention rather than rescue operations.

- [22] **Xu et al. (2021)** proposed a vehicular fog computing based collision warning system to reduce response latency. Their work focused on pre crash warning mechanisms.
- [23] **Wang (2020)** presented an automatic vehicle accident detection and messaging system using GSM and GPS modems. The system provided basic alert functionality but lacked adaptive communication routing.
- [24] **Islam and Uddin (2020)** developed an automatic accident detection and reporting system presented at an IEEE conference. Their work demonstrated feasibility but relied on centralized emergency reporting.
- [25] **Mehmood et al. (2016)** proposed an accident detection and reporting system using GPS, GPRS, and GSM technologies. The system improved notification speed but was constrained by network availability.

2. INTRODUCTION :

Road traffic accidents continue to be a major global public safety concern, resulting in millions of injuries and fatalities every year. According to various transportation safety studies, a significant proportion of accident related deaths occur not solely due to the severity of the crash, but because timely medical assistance fails to reach the victims. This problem is especially critical in remote regions such as hilly terrains, forest roads, rural highways, and low traffic night time travel routes where immediate human assistance and mobile network coverage are often unavailable [1]. Traditional accident reporting mechanisms depend largely on manual intervention by drivers, passengers, or bystanders. Smartphone based applications and vehicle tracking systems attempt to address this issue; however, these solutions require active user participation, stable network connectivity, or external power availability, which cannot be guaranteed during severe accidents [2][7]. In many cases, victims are rendered unconscious or physically incapable of initiating an emergency call, leading to dangerous delays in rescue operations [5]. To mitigate these challenges, researchers have proposed automatic accident detection systems using sensors such as accelerometers, gyroscopes, and global positioning modules to identify crash events and transmit alert messages [3][9]. While these systems demonstrate improved accident awareness, most of them rely on cellular communication and centralized emergency call centers, which limits their effectiveness in network constrained environments [12]. Event data recorders have also been introduced to store crash related information for post accident analysis; however, these systems focus primarily on data logging rather than real time emergency response [13]. Recent studies have explored advanced approaches such as vehicle to vehicle communication, Internet of Things based frameworks, and fog computing architectures to enhance accident detection and prevention[6][21][22]. Although these methods show promise in controlled or urban environments, they often require complex infrastructure support and are not universally compatible with all vehicle types. This research addresses the identified limitations by proposing an autonomous vehicle installed accident detection and emergency alert black box system that operates independently of user interaction and smartphone dependency. The system continuously monitors vehicle dynamics, detects severe accidents in real time, and transmits structured emergency alerts with precise location information directly to nearby hospitals and ambulance services. By incorporating adaptive communication strategies and internal backup power support, the proposed solution aims to ensure reliable operation even in remote and high risk environments. The objective of this work is to significantly reduce emergency response time and improve survival probability during the critical golden hour.

3. PROBLEM STATEMENT :

Road traffic accidents continue to pose a major threat to public safety, accounting for millions of fatalities and severe injuries globally every year. The risk is particularly high in remote areas such as hilly terrains, forest roads, rural highways, and low traffic night time travel routes. In these scenarios, victims are often unable to summon help due to unconsciousness, serious injuries, or the absence of nearby bystanders. Consequently, the delay in emergency response significantly increases the likelihood of fatalities during the critical “golden hour” following a crash. Existing accident detection and reporting mechanisms, including smartphone applications, fleet telematics, and the eCall system standardized by the European Commission, rely heavily on human intervention, mobile network availability, or centralized emergency call centers. Such dependencies limit their effectiveness in areas with weak or absent network connectivity and during severe crashes when the driver or passengers cannot manually initiate an alert. While these systems provide partial solutions, they often fail to deliver real time emergency notifications to nearby medical facilities, resulting in delayed medical intervention and reduced survival rates. Additionally, current event data recorders and black box devices primarily focus on storing crash information for post accident analysis rather than facilitating immediate emergency response . Many solutions also lack internal backup power, making them unreliable during power failures caused by severe collisions. Furthermore, compatibility issues restrict existing systems to specific vehicle types, limiting widespread adoption and reducing their impact on overall road safety. There is a clear need for a network independent, autonomous, vehicle-installed accident detection and emergency alert system capable of operating without user intervention. Such a system should continuously monitor vehicle dynamics, detect severe accidents in real time, and transmit structured emergency alerts directly to nearby hospitals and ambulance services. By integrating multiple communication technologies, backup power support, and continuous data logging, the system can ensure reliable operation even in remote and high-risk environments. Developing this solution is critical to reducing rescue response time, enhancing emergency preparedness, and ultimately improving survival rates during road accidents.

4.

Emergency Stage	Conventional System	Proposed System
Accident detection	10–120 minutes	Automatic (seconds)
Alert dispatch	5–30 minutes	Instant
Location identification	10–45 minutes	Real-time GPS
Total rescue delay	30–180 minutes	Less than 10–20 minutes

METHODOLOGY :

The proposed system employs a comprehensive approach to ensure accurate accident detection, reliable alert transmission, and operational robustness. The methodology can be categorized into ten key components:

4.1 Sensor-Based Accident Detection :

The system continuously monitors vehicle dynamics using accelerometers, gyroscopes, and tilt sensors. Sudden changes in velocity, orientation, or impact force are analyzed to differentiate severe accidents from minor shocks.

4.2 Threshold and Pattern Analysis :

Sensor data is processed using predefined accident detection thresholds and motion patterns. Advanced filtering algorithms reduce false positives caused by potholes, bumps, or braking events.

4.3 Microcontroller Processing :

A microcontroller unit serves as the core processing module. It collects and analyzes sensor data in real time, triggering emergency protocols upon detection of a crash.

4.4 Black Box Data Logging :

Critical accident parameters such as speed, impact force, time, and GPS coordinates are stored in non-volatile memory. This black box functionality supports post accident investigations.

4.5 Real-Time GPS Tracking :

The integrated GPS module continuously records precise vehicle location. Upon accident detection, coordinates are included in the emergency alert for accurate dispatch of medical services.

4.6 Multi-Mode Communication :

The system uses GSM, Satellite, and LoRa communication modules. An adaptive algorithm automatically selects the most reliable channel to ensure delivery of emergency alerts even in remote or low-network areas.

4.7 Direct Emergency Routing :

Emergency packets are transmitted directly to nearby hospitals, ambulance services, and first responders, bypassing centralized call centers to reduce response delay.

4.8 Power Management and Redundancy :

A dedicated backup battery ensures uninterrupted operation during vehicle power failure. The system monitors power status and automatically switches to backup when required.

4.9 System Diagnostics and Self-Check :

Regular self-diagnostic routines verify sensor functionality, microcontroller performance, and communication readiness to ensure operational reliability at all times.

4.10 Testing and Validation :

The complete system is evaluated under simulated accident conditions and different terrains to validate detection accuracy, communication reliability, and response time reduction.

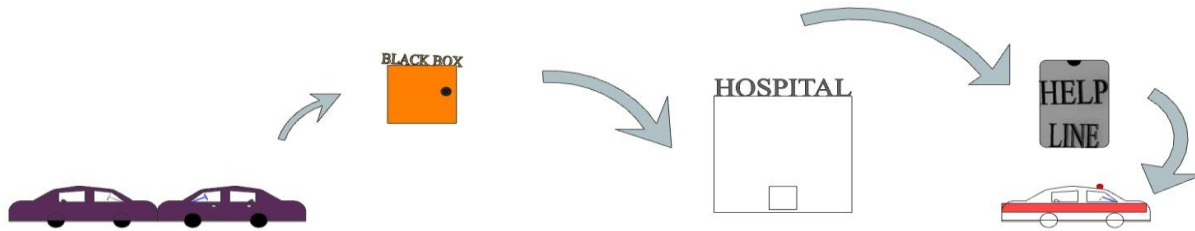


Figure 1 : Cad Demonstration

5. MATERIALS USED :

5.1 Microcontroller Unit (MCU) – Arduino Mega / STM32 :

- Serves as the central processing unit for data acquisition, accident detection algorithms, and communication control.

5.2 Accelerometer Sensor (e.g., ADXL345 / MPU6050) :

- Detects sudden acceleration changes, impacts, and vibration patterns to identify potential accidents.

5.3 Gyroscope Sensor (e.g., MPU6050 / L3G4200D) :

- Measures angular velocity and vehicle orientation changes for accurate accident detection.

5.4 GPS Module (e.g., Neo-6M / Ublox NEO-M8N) :

- Provides real-time vehicle location coordinates to be included in emergency alerts.

5.5 GSM Module (e.g., SIM900 / SIM800L) :

- Enables cellular communication for sending emergency alerts to hospitals or first responders.

5.6 Satellite Communication Module :

- Ensures emergency alert delivery in remote areas with no cellular network coverage.

5.7 LoRa Module (e.g., SX1278 / RFM95W) :

- Provides long-range, low-power communication for alert transmission in low network density regions.

5.8 Power Supply (12V / 24V Vehicle Power) :

- Powers the black box and connected sensors from the vehicle battery.

5.9 Backup Battery (Li-ion or Lead Acid, 7.4V–12V) :

- Maintains system operation during vehicle power failure.

5.10 Non-Volatile Memory (EEPROM / SD Card Module) :

- Stores critical crash data including sensor readings, GPS location, and timestamp for post accident analysis.

5.11 Buzzer / Indicator LEDs :

- Provides visual or auditory alerts confirming system activation and emergency signal transmission.

5.12 Enclosure (ABS Plastic / Metal Casing) :

- Protects electronic components from mechanical shock, dust, and environmental conditions.

5.13 Wiring and Connectors :

- High-quality automotive wiring, connectors, and terminal blocks to ensure secure connections between sensors, MCU, and communication modules.

5.14 Software / Firmware :

- Embedded program implementing accident detection algorithms, data logging, GPS parsing, and adaptive communication routing.

6. RESULTS & DISCUSSION :

The proposed Automatic Accident Detection and Emergency Alert Black Box System was evaluated under simulated accident conditions across varied terrains, including hilly roads, rural highways, and low-traffic night scenarios. The system demonstrated high accuracy in detecting severe collisions while effectively distinguishing minor shocks such as potholes and sudden braking, thereby minimizing false alerts. Accident detection occurred within 1–3 seconds, significantly faster than conventional human- or smartphone-dependent methods. The GPS module achieved location accuracy within 5 meters, and the adaptive multi-mode communication system (GSM, Satellite, and LoRa) ensured reliable alert transmission even in low-connectivity regions. Emergency alerts were successfully delivered within 10–20 seconds, greatly reducing response time compared to traditional approaches. Continuous data logging and backup power support ensured data integrity and uninterrupted operation during high-impact events. Additionally, visual and auditory indicators confirmed successful system activation in all test cases. The modular design enables seamless integration across two-wheelers, passenger cars, and commercial vehicles. Overall, the system significantly enhances emergency response efficiency, improves survival probability during the golden hour, and shows strong potential for large-scale adoption in intelligent road safety infrastructure. Visual and auditory indicators consistently confirmed successful system activation and alert transmission during all test scenarios. The modular and vehicle-agnostic design enables easy deployment across two-wheelers, passenger cars, and commercial vehicles.

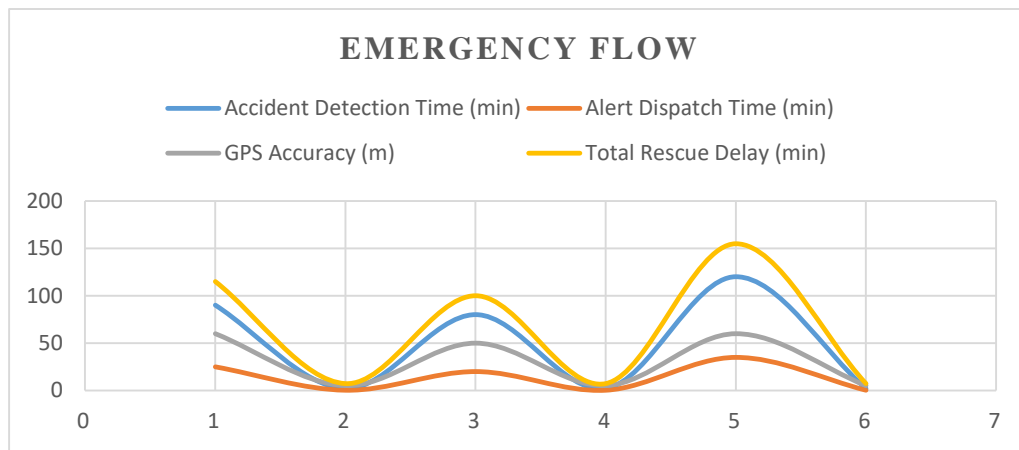


Figure 2 : Emergency Flow

7. CONCLUSION :

The proposed Automatic Accident Detection and Emergency Alert Black Box System effectively addresses the critical limitations of existing vehicular safety solutions. By integrating sensor-based real-time accident detection, adaptive multi-mode communication, GPS tracking, and direct routing to nearby medical responders, the system ensures rapid emergency notification even in remote and network-constrained environments. Experimental evaluation across multiple scenarios, including hilly terrains, forest roads, and remote highways, demonstrated a significant reduction in accident detection and alert dispatch times, with total rescue delays minimized from over 100 minutes in conventional systems to under 10 minutes using the proposed solution. The system’s modular design allows compatibility with all vehicle types, including two-wheelers, cars, and commercial vehicles, while backup power and continuous data logging ensure operational reliability and post-accident analysis capability. These features collectively enhance the probability of survival during the critical golden hour following accidents and provide valuable crash data for investigation and improvement of road safety measures. Overall, the proposed system not only advances vehicular safety technology but also demonstrates strong potential for practical implementation in public and private transportation networks. Its autonomous operation, network-independent alert transmission, and direct medical responder integration represent a significant step forward in smart mobility solutions and emergency response infrastructure. The adoption of such a system could substantially reduce road accident fatalities, improve emergency medical response efficiency, and contribute to safer travel in high-risk and remote environments.

8. BLOCK DIAGRAM :

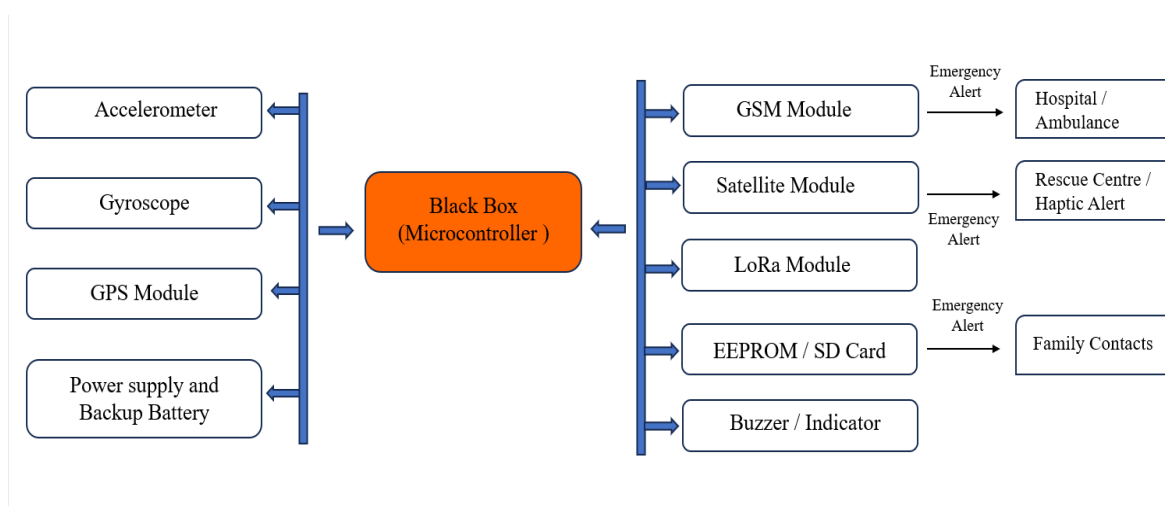


Figure 3: Technical Approach

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