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Design and Implementation of an IoT-Based Smart Emergency Alert System

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Abstract

Road accidents on highways often result in delayed emergency response due to the absence of immediate accident reporting mechanisms, particularly in remote areas with limited communication infrastructure. This delay can significantly affect the chances of timely medical assistance and rescue operations. To address this challenge, this paper proposes the Smart-Rescue System, an IoT-based emergency response solution designed to detect accidents automatically and transmit real-time alerts to emergency services. The system integrates an ESP32 microcontroller with motion sensors, GPS, and GSM communication modules to continuously monitor vehicle conditions and detect abnormal events such as sudden impacts or hazardous situations. When an emergency is identified, the system automatically sends an alert message containing the precise geographic location of the incident to nearby hospitals, rescue teams, and predefined contacts. Experimental evaluation of the prototype demonstrates that the system can rapidly identify accident conditions and significantly reduce emergency response delays. The proposed system can be integrated into intelligent transportation infrastructures and smart highway safety frameworks to enhance emergency management and improve overall road safety.

Keywords: *Emergency alert system; ESP32; GPS-enabled tracking; GSM-based notification system; Internet of Things (IoT)*

1. Introduction

India's highways and urban roads have witnessed a sharp rise in accidents, vehicle breakdowns, and criminal activities such as thefts. According to recent road safety reports, thousands of lives are lost every year due to delayed emergency response, inefficient including limited network coverage, dependence on systems. Emergency assistance is often hindered by infrastructure challenges manual reporting, and lack of real-time communication, and the absence of unified rescue management, location data.These growing challenges highlight the need for a technological solution capable of automating emergency detection and response. The Internet of Things (IoT) offers a promising approach by enabling real-time sensing, communication, and decision-making through interconnected devices. By integrating sensors, GPS, and GSM modules, IoT-based systems can autonomously detect incidents and immediately communicate with emergency authorities, reducing delays that often lead to severe casualties and property loss. This paper presents a literature survey on IoT- and AI-based accident detection and alert systems, analyzing their methodologies, advantages, and limitations. Further, a proposed Smart-Rescue system is introduced — an IoT driven framework designed to detect accidents, vehicle breakdowns, and fire incidents while transmitting automated alerts to hospitals, police, and towing services using the ESP32 microcontroller.

2. Literature Review

C. V. Suresh Babu and Maclin Vinola P. (2024) proposed an "IoT-Based Smart Accident Detection and Early Warning System" that focuses on improving road safety using advanced IoT technologies. Their system utilizes various IoT sensors and surveillance cameras integrated with

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deep learning algorithms to detect accidents automatically and provide early warnings. The methodology combines vehicle monitoring systems with centralized databases of hospitals and police departments to ensure quick notification and response. Once an accident is detected, the system processes sensor data and camera feeds using AI models to confirm the incident and send alerts to relevant authorities. One of the key advantages of this approach is its ability to improve detection accuracy through artificial intelligence and provide early warnings that can help reduce casualties. Additionally, the integration with emergency infrastructure ensures faster coordination among rescue services. However, the system requires extensive datasets for training the deep learning models, and the integration of multiple devices and networks increases system complexity and infrastructure requirements. Abu S. M. Mohsin and Munyem Ahammad Muyeed (2024) introduced an "IoT Based Smart Emergency Response System (SERS)" designed to monitor vehicles, homes, and health conditions through a unified IoT framework. The proposed system collects data from multiple sensors installed in vehicles, residential environments, and wearable health devices. These data streams are integrated through cloud platforms where data fusion techniques are applied to monitor and analyze the information in real time. [1-2] The system aims to provide a comprehensive monitoring solution capable of responding to different types of emergencies, including vehicle accidents, home hazards, and health emergencies. The major advantage of this system is its multi-domain coverage and scalability, allowing it to expand across different environments and applications. It also improves emergency response efficiency by combining various monitoring systems into a single platform. However, integrating multiple domains and data sources increases system complexity and raises concerns about data privacy and security, especially when personal health and location data are transmitted through cloud-based services. Pathik N. Vetal (2023) presented an "AI Enabled Accident Detection and Alert System Using IoT and Deep Learning." The proposed system utilizes IoT sensors to collect real-time vehicle data such as vibration, impact force, and motion parameters. These data are processed using deep learning models to identify patterns associated with road accidents. The integration of artificial intelligence enables the system to differentiate between normal driving conditions and actual accidents, improving detection accuracy. When an accident is detected, the system automatically sends alert notifications to emergency responders along with location information obtained through GPS modules. One of the primary advantages of this system is the intelligent automation provided by deep learning, which reduces human intervention and enables rapid emergency response. However, the implementation of deep learning algorithms requires high computational resources and powerful processing units. This may increase the cost and complexity of the system, making it less suitable for low-cost embedded platforms or resource-limited environments.[4] Muhammad Ahmad Baballe (2022) conducted a comprehensive study titled "Accident Detection and Alerting Systems: A Study", which reviews different technologies used in accident detection and emergency alert systems. The paper analyzes several detection approaches, including sensor-based detection, smartphone-based applications, camera surveillance systems, and IoT-based monitoring solutions. The study compares these technologies in terms of reliability, response time, implementation complexity, and practical applicability. One of the key contributions of this research is its broad comparative analysis, which provides valuable insights into the strengths and limitations of existing accident detection systems. The paper highlights how integrating IoT devices, GPS tracking, and automated alert mechanisms can significantly improve emergency response efficiency. However, since the research is primarily a survey and review study, it does not introduce a new experimental system or present original implementation results. [2] Therefore, while the study offers theoretical insights and comparisons, it lacks practical experimentation or prototype development. Shivani Sharma (2021) proposed an "IoT Based Car Accident Detection and Notification Algorithm" aimed at improving emergency response

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times during road accidents. The system uses various sensors installed within the vehicle to detect sudden impacts, abnormal acceleration, or unusual motion patterns that may indicate an accident. Once such an event is detected, an algorithm processes the sensor data to verify the incident and automatically sends notification alerts to emergency contacts and nearby rescue services. The key advantage of this system is the automated alert mechanism, which significantly reduces the time required to report accidents compared to manual reporting methods. Faster notification helps emergency teams reach the accident site more quickly and potentially save lives. However, the system may sometimes generate false alarms due to sudden braking or rough road conditions. Additionally, its dependence on stable network connectivity can limit its effectiveness in remote areas where communication infrastructure is weak. Chethan N. Vetal (2020) presented the "Emergency Assistance Accident Detection and Alert System" in an IEEE publication. The proposed system employs IoT sensors combined with GPS modules to detect accidents and automatically notify emergency contacts. The sensors continuously monitor parameters such as vibration, collision impact, and sudden vehicle movement. When an accident is detected, the system immediately retrieves the vehicle's geographic location through the GPS module and sends alert messages containing the location coordinates to predefined emergency contacts or rescue authorities. The main advantage of this system is its reliability in detecting accidents automatically and providing real-time GPS tracking, which helps responders locate the accident site quickly. The system improves emergency response time and reduces the dependency on manual reporting by victims or witnesses. However, the system relies heavily on continuous GPS signal availability, and in remote or mountainous regions where satellite signals may be weak, there could be delays in transmitting accurate location information.[2-3]

Table 1 Comparative Analysis of Existing Research

Ref. Paper No.	Technique Used	Key Points
[1]	Deep learning + IoT sensors	High accuracy, integrated alerts; high computation cost.
[2]	IoT + cloud data fusion	Multi-domain monitoring; cloud dependency, privacy issues.
[3]	AI + sensor-based detection	Automatic GPS alerts; high processing requirement.
[4]	Survey of detection methods	Comparative analysis; no implementation.
[5]	Rule-based sensor system	Low-cost, embedded-friendly; false alarms possible.
[6]	IoT + GPS tracking system	Real-time alerts; depends on GPS availability.
Proposed System	Lightweight IoT-based detection	Low power, GSM + GPS alerts; fully integrated system.

3. Proposed Methodology

The Smart-Rescue system is designed to provide an automated emergency response mechanism for vehicle accidents and hazardous situations. Previous studies have demonstrated the use of IoT for accident detection and emergency notification. Gaikwad and Patil (2019) proposed a system that detects accidents and sends alerts to emergency contacts, which forms the basis for the proposed system design. The architecture integrates sensing devices, a processing unit, and communication modules to enable real-time event detection and alert generation. The overall system architecture, illustrated in Fig. 1, represents the interaction among different hardware components

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that collectively perform monitoring, processing, and emergency notification tasks. [4] The system is structured into four main functional units:

- **Sensor Unit**

The sensor unit is responsible for continuously monitoring the vehicle's motion and surrounding environmental conditions. An MPU6050 module, which combines an accelerometer and gyroscope, is used to detect sudden impacts, abnormal vibrations, or drastic orientation changes that may indicate a collision. In addition, a flame sensor is included to detect the presence of fire or excessive heat that may occur after an accident.

- **Processing Unit (ESP32)**

The ESP32 microcontroller serves as the central processing component of the system. It collects sensor readings, evaluates the data using predefined decision logic, and determines whether an abnormal event has occurred. The ESP32 also manages communication with peripheral modules and coordinates the overall system operation.

- **Communication Unit**

To facilitate emergency communication, the system incorporates both GSM and GPS modules. The GPS module obtains real-time geographic coordinates of the vehicle, while the GSM module is used to transmit alert messages. When an emergency is detected, the system automatically sends a notification containing the location information and alert details to predefined contacts and emergency response services.

- **Response Unit**

The response unit ensures that emergency notifications are delivered promptly to relevant authorities and family members. In addition to external communication, a buzzer is activated locally to alert the vehicle occupants of the detected emergency condition.

Through the integration of sensing, processing, and communication modules, the proposed architecture enables reliable detection of hazardous events and rapid transmission of emergency alerts, thereby helping reduce rescue response time.

4. Implementation

The Smart-Rescue system follows a combined hardware and software methodology to support continuous monitoring and automated emergency notification. The methodology focuses on accurate event detection, reliable communication, and uninterrupted system operation. The overall working procedure includes sensor data acquisition, event verification, location retrieval, and alert transmission.

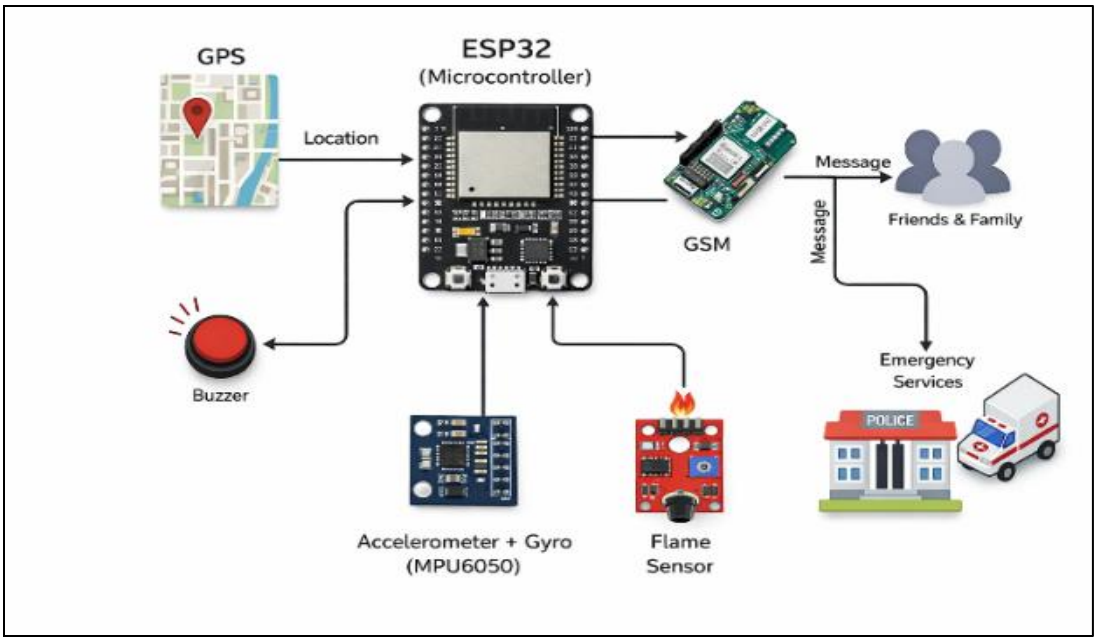

Figure 1 Proposed Architecture of Smart-Rescue system

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4.1.Hardware Implementation

The Smart-Rescue system is implemented using an embedded hardware architecture centered around the ESP32 microcontroller. The ESP32 serves as the main processing unit and coordinates data acquisition from sensors as well as communication with external modules. The hardware configuration enables continuous monitoring of vehicle conditions and supports automated emergency alert generation. The primary hardware components used in the system are described below.

Major hardware components include:

- **ESP32 Microcontroller:**

Acts as the central controller of the system. It collects sensor readings, evaluates emergency conditions using predefined logic, and manages communication with the GPS and GSM modules.

- **MPU6050 Sensor Module:**

This module integrates an accelerometer and gyroscope to measure vehicle acceleration and orientation. Sudden changes in these parameters may indicate abnormal motion patterns or collision events.

- **Flame Sensor:**

The flame sensor detects the presence of fire or excessive heat that may occur during or after a vehicle accident.
It enhances the system's ability to identify hazardous situations.

- **GPS Module (NEO-M8N):**

Provides real-time geographic coordinates of the vehicle. The location information is included in the emergency alert message to help responders reach the accident site quickly.

- **GSM Module (SIM900L):**

Enables wireless communication by sending automated alert messages to predefined emergency contacts and response services.

- **Buzzer:**

An audible buzzer is used to generate an immediate alert within the vehicle when an emergency condition is detected. [5]

4.2.Software Implementation

The software for the Smart-Rescue system is developed using the Arduino IDE with Embedded C/C++ programming. The firmware is designed to manage sensor data acquisition, evaluate emergency conditions, and coordinate communication between system components. The program continuously monitors sensor inputs and applies predefined threshold logic to identify potential accident or fire events. Several software libraries are used to simplify hardware communication and data processing.[5-6]
Libraries used in the implementation include:

- **Wire.h:**

Provides I²C communication between the ESP32 and the MPU6050 motion sensor.

- **TinyGPS++:**

Processes GPS data and extracts useful information such as latitude and longitude coordinates.

- **SoftwareSerial.h:**

Enables serial communication between the ESP32 microcontroller and the GSM module.
The firmware continuously reads sensor values and compares them with predefined threshold levels. When the sensor readings exceed these limits, the system interprets the event as a potential emergency. The ESP32 then retrieves the current GPS location and composes an automated alert message containing the location coordinates and emergency information. This message is transmitted through the GSM module to predefined emergency contacts, ensuring timely notification and response.

4.3.Operational Workflow

The operational workflow of the proposed Smart-Rescue system is illustrated in Fig. 2. Upon powering up, the system initializes all connected sensors and establishes serial communication with the GPS and GSM modules. Once initialization is complete, the system enters continuous monitoring mode. The accelerometer and gyroscope continuously track vehicle motion, while the flame sensor monitors the surrounding environment for fire-related anomalies. Sensor readings are sampled at regular intervals and compared against predefined threshold values to identify potential emergency conditions. To reduce false triggers caused by road irregularities or sharp turns, a multi-sensor verification mechanism is employed. When an abnormal condition is confirmed, the ESP32 activates the buzzer to alert

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vehicle occupants and simultaneously retrieves the current GPS coordinates. The GSM module then transmits an automated alert message containing the location details, type of emergency, and timestamp to predefined emergency contacts such as family members, hospitals, police services, and towing authorities. A retry mechanism is implemented to ensure message delivery in case of temporary network instability. All detected events are time-stamped, and the system stores the last known coordinates if GPS connectivity is momentarily unavailable. After completing the alert transmission process, the system resets to its monitoring state, enabling uninterrupted operation and continuous readiness for subsequent emergencies. This systematic and real-time workflow significantly reduces response delays and enhances the effectiveness of emergency assistance.

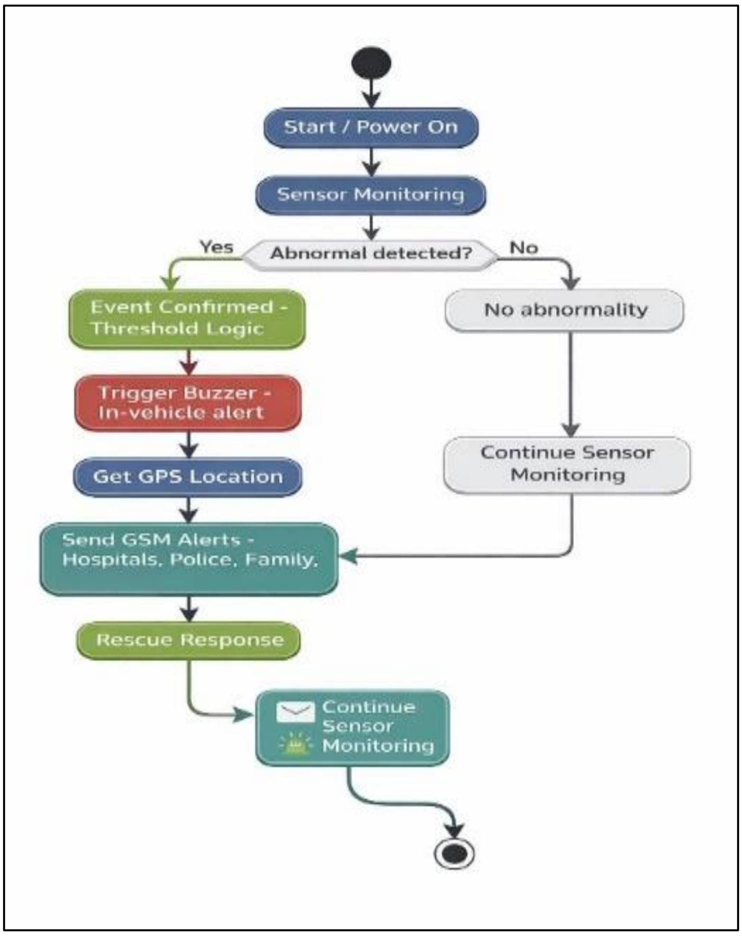

Figure 2 System Workflow

4.4.Mathematical Model

The proposed system utilizes sensor data and threshold-based decision logic to detect emergency conditions such as accidents or fire hazards. The mathematical model is formulated based on the inputs obtained from the accelerometer, GPS module, and other sensors integrated with the ESP32 microcontroller. [8-9]The acceleration magnitude of the vehicle is computed using three-axis accelerometer data as:

$$A = \sqrt{x^2 + y^2 + z^2}$$

where x, y, and z represent acceleration components along the respective axes. A sudden spike in

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acceleration indicates a potential collision or abnormal event.
To detect an accident, a predefined threshold A_{th} is used:

If A > A_{th}, then Accident Detected
Additionally, tilt or orientation changes can be analyzed using gyroscope data to improve detection accuracy.The system also incorporates location tracking using GPS coordinates, represented as:

L = (lat, lon)
where lat and lon denote latitude and longitude respectively. Once an abnormal condition is detected, the system triggers an alert mechanism and transmits the location information to predefined emergency contacts.[7]

For fire detection, sensor output F is compared with a threshold F_{th}:

If F > F_{th}, then Fire Detected

Thus, the mathematical model combines sensor data acquisition, threshold-based evaluation, and decision-making logic to ensure timely detection and response to emergency situations.[8]

5. Results and Discussion

5.1.Results

The performance of the proposed Smart-Rescue system was evaluated under various simulated scenarios, including vehicle collision, fire detection, and normal driving conditions. During accident and fire simulations, the system consistently detected abnormal events and generated automated alerts within an average response time of 3–4 seconds, demonstrating timely emergency notification. The GPS module provided real-time location information with an average positional accuracy of approximately ±5–6 meters, which is sufficient for effective emergency response and navigation by rescue services. Alert messages containing location coordinates and event details were successfully transmitted through the GSM module to predefined emergency contacts. Under normal driving conditions, the system remained stable and did not generate false alerts. This confirms the effectiveness of the multi-sensor threshold validation logic in distinguishing between routine vehicle movements and actual emergency situations. The buzzer alert mechanism also functioned reliably, providing immediate in vehicle notification upon event confirmation. [10]

5.2. Discussion and Performance Analysis

A review of existing IoT-based emergency and accident detection systems reveals several common limitations. Many systems rely on a single sensing mechanism, such as vibration detection, which often results in false alarms due to road irregularities. Other approaches are highly dependent on continuous internet connectivity, making them unreliable in remote or low-signal environments. In addition, several systems are limited to accident detection alone and do not address other critical scenarios such as fire hazards or vehicle breakdowns. App-based solutions further increase response time by requiring manual user confirmation before alert transmission. The proposed Smart-Rescue system addresses these challenges through a multi-sensor fusion approach that combines accelerometer, gyroscope, and flame sensor data to improve detection accuracy and reduce false triggers. The integration of GSM and GPS modules enables reliable alert transmission and precise location tracking without dependence on smartphone applications or user intervention. By automatically notifying hospitals, police authorities, family members, and towing services simultaneously, the system minimizes response delays and enhances rescue coordination. Furthermore, the system operates autonomously once powered on, ensuring continuous monitoring and immediate response during emergencies. The modular ESP32-based architecture allows future enhancements such as cloud integration, AI-based event prediction, and mobile application support, improving scalability and long-term usability. Overall, the experimental results and comparative analysis indicate that Smart-Rescue offers improved reliability, faster response time, and broader emergency coverage compared to conventional IoT-based emergency detection systems. Its practical design and real-time operation make it a viable solution for enhancing road safety and emergency management. [11-12]

Conclusion and Future Scope

This paper presented the design and implementation of an IoT-based smart emergency response system aimed at enhancing vehicle and highway safety. The proposed Smart-ResQ framework integrates multiple sensors with an ESP32 microcontroller, along with GSM and GPS modules, to enable continuous monitoring, automatic emergency detection, and real-time alert transmission. The system effectively identifies accident and fire scenarios and communicates precise location details to predefined emergency contacts without requiring manual intervention. Experimental evaluation demonstrated that the system achieves reliable emergency detection and rapid response within a few seconds, validating its effectiveness in time-critical situations. The results indicate that the proposed approach reduces dependence on human intervention, minimizes response delays, and supports faster coordination with emergency authorities. These outcomes highlight the potential of Smart-Rescue as a practical and dependable solution for improving passenger safety and emergency management. While the prototype implementation shows promising performance, further enhancements can be incorporated to extend its capabilities. Future work may include the development of a dedicated mobile application for live tracking and real-time notifications. Integration of cloud-based storage can support incident logging, data analytics, and identification of accident-prone zones. The addition of a camera module could facilitate visual evidence capture and improve rescue coordination. Voice-enabled SOS features may allow hands-free interaction during emergencies. Furthermore, machine learning techniques can be explored to enable predictive analysis of high-risk areas and to provide intelligent route safety recommendations. In conclusion, the Smart-Rescue system offers a scalable and adaptable foundation for next-generation intelligent transportation and emergency response solutions, with significant potential for real-world deployment and further technological advancement.

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