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Self-Powered Roadside Accident Detection and Alert Beacon Using ESP32, GPS and GSM

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Abstract: *This paper presents a Self-Powered Roadside Accident Detection and Alert Beacon, an embedded system designed to detect accidents and automatically notify emergency contacts with accurate location details. The system uses an ESP32 microcontroller, vibration sensor, GPS module, and GSM communication module to detect accident events and transmit alerts. When a sudden impact is detected by the vibration sensor, the microcontroller evaluates the sensor value with a predefined threshold. If the value exceeds the threshold level, the system interprets it as an accident. The GPS module retrieves the accident location coordinates, and the GSM module sends an SMS alert containing the location information to predefined emergency contacts. A LCD display provides real-time system information such as GPS status and sensor readings. The proposed system operates using a self-powered energy source, allowing deployment in remote roadside areas where continuous electrical supply may not be available. The system helps reduce emergency response time and improves road safety by enabling automatic accident reporting.*

Keywords: Accident Detection System, ESP32 Microcontroller, GPS Tracking, GSM Communication, Embedded Systems, Road Safety, Intelligent Transportation Systems

I. INTRODUCTION

Road traffic accidents remain one of the leading causes of fatalities worldwide, with millions of injuries reported every year due to delayed emergency response and lack of immediate accident reporting systems [1]. Rapid urbanisation, increasing vehicle density, and inadequate real-time monitoring systems have further intensified the need for intelligent accident detection technologies. In many cases, victims are unable to notify emergency services due to severe injuries or accidents occurring in remote areas, which significantly increases mortality rates. Recent advancements in embedded systems, wireless communication technologies, and low-cost sensors have enabled the development of automated accident detection and alert systems that can improve emergency response time and enhance road safety.

Modern accident detection systems commonly rely on vehicle-mounted sensors, smartphone-based monitoring, or centralized traffic surveillance systems. While these approaches provide certain advantages, they also present limitations such as dependency on user devices, high infrastructure costs, and restricted coverage in remote areas. In contrast, roadside intelligent monitoring systems offer a promising alternative by enabling continuous monitoring of accident-prone locations without relying on vehicle- based equipment. The availability of low-cost microcontrollers such as ESP32, along with compact GPS receivers, vibration sensors, and GSM communication modules, allows the development of efficient accident detection systems capable of transmitting real-time alerts with precise location information.

Embedded systems with integrated communication modules can provide autonomous monitoring and rapid alert generation during accident events. When combined with location tracking technologies, these systems can transmit critical accident information to emergency responders, enabling faster medical assistance. Additionally, the integration of self-powered energy sources allows such systems to operate independently in remote roadside environments where a continuous electrical supply may not be available.

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This work presents a Self-Powered Roadside Accident Alert Beacon, designed to automatically detect accident events and notify emergency services using location-based communication. The system integrates an ESP32 microcontroller, vibration/impact sensor, GPS module, GSM communication module, and a 16×2 LCD display to create a reliable accident detection and alert platform. The vibration sensor continuously monitors sudden mechanical shocks associated with vehicle collisions. When the detected vibration exceeds a predefined threshold value, the ESP32 processes the signal and activates the alert mechanism. The GPS module retrieves the exact geographical coordinates of the accident location, and the GSM module transmits an emergency message containing the accident information and location details to predefined contacts.

The principal contributions of this paper are:

• Design and implementation of a self-powered roadside accident detection beacon capable of operating autonomously in remote locations.

• Integration of ESP32-based embedded control architecture with vibration sensing for accurate accident event detection.

• Development of a GPS-enabled location tracking system to identify precise accident coordinates.

• Implementation of a GSM-based communication module for automatic transmission of emergency alerts.

• Real-time system monitoring through a 16×2 LCD display showing sensor status, GPS connectivity, and alert notifications.

The remainder of this paper is organised as follows. Section II reviews related work in accident detection systems. Section III describes the hardware architecture and system components. Section IV explains the system operation and software design. Section V presents experimental results and system performance evaluation. Section VI discusses the findings, and Section VII concludes the paper.

II. RELATED WORK

Accident detection and emergency alert systems have been widely studied in recent years with the aim of reducing response time and improving road safety. Several approaches have been proposed using accelerometers, GPS tracking, and wireless communication technologies to automatically detect accident events and transmit alerts.Early research focused on vehicle- mounted accident detection systems that use accelerometers and vibration sensors to identify sudden collisions. These systems integrate GPS modules and GSM communication to send location information to emergency contacts when an accident occurs. While these solutions provide reliable accident detection, they require installation inside individual vehicles, which increases system cost and maintenance requirements.

Smartphone-based accident detection systems have also been developed using built-in accelerometers and GPS sensors. These applications detect abnormal movements of the phone and automatically send alerts to emergency contacts. However, these systems depend heavily on the availability and condition of the user's mobile device. In severe accidents, the smartphone may be damaged or unable to transmit alerts.

More recent studies have explored IoT-based accident monitoring systems that use embedded microcontrollers and wireless communication networks to transmit accident data to cloud platforms. These systems enable remote monitoring and real-time data analysis but often require reliable internet connectivity and complex infrastructure.

Despite these advancements, there is limited research focusing on roadside accident detection infrastructure capable of monitoring accident-prone locations independently. A roadside beacon system can continuously monitor vibrations caused by collisions and automatically notify authorities without relying on vehicle-based hardware. The proposed Self-Powered Roadside Accident Alert Beacon addresses this gap by integrating vibration sensing, GPS location tracking, and GSM communication in an autonomous roadside unit that can operate in remote environments.

III. SYSTEM ARCHITECTURE AND HARDWARE DESIGN

A. Overall System Overview:

The proposed Self-Powered Roadside Accident Alert Beacon consists of three major subsystems: (1) the embedded accident detection unit based on the ESP32 microcontroller with vibration sensing peripherals; (2) the GPS and GSM communication subsystem responsible for location acquisition and alert transmission; and (3) the user interface and monitoring subsystem implemented through a 16×2 LCD display.

The ESP32 functions as the central control unit that continuously monitors vibration sensor data and evaluates potential accident events. When the detected vibration exceeds a predefined threshold value, the ESP32 activates the alert process. The GPS module retrieves the geographical coordinates of the accident location, while the GSM module transmits an emergency SMS containing the location details to predefined contacts such as emergency responders or nearby authorities. The LCD display provides real- time monitoring of system status including GPS connectivity and sensor readings.

B. Embedded Control Unit — ESP32 Microcontroller:

The ESP32 microcontroller serves as the primary processing unit of the system. It is a low-power, high-performance microcontroller widely used in embedded and IoT applications. The ESP32 integrates multiple communication interfaces including UART, SPI, and I²C, enabling efficient interaction with peripheral modules.

In the proposed system, the ESP32 performs the following tasks:

- Continuous monitoring of vibration sensor data
- Comparison of sensor readings with predefined threshold values
- Processing of accident detection logic
- Communication with GPS and GSM modules through UART

The ESP32 executes the accident detection algorithm in real time and coordinates the communication between sensing and alert subsystems.

C. Impact Detection Module — Vibration Sensor:

The accident detection mechanism is implemented using a vibration or impact sensor capable of detecting sudden mechanical shocks caused by vehicle collisions. The sensor generates an electrical signal proportional to the vibration intensity.

Under normal conditions, the vibration values remain below the predefined threshold level. When a strong impact occurs due to an accident, the sensor output increases significantly and triggers the accident detection algorithm implemented in the ESP32. This module enables rapid identification of collision events occurring near the roadside beacon.

D. GPS Location Tracking Module — NEO-6M GPS Receiver:

The NEO-6M GPS module provides accurate geographic positioning using satellite-based navigation signals. The module communicates with the ESP32 through a UART interface and outputs location information in the NMEA data format.

The GPS receiver provides the parameters Latitude and longitude coordinates, Altitude information, Satellite count and signal quality

Once an accident is detected, the ESP32 retrieves the location coordinates from the GPS module and includes them in the emergency alert message transmitted through the GSM module.

E. GSM Communication Module — SIM900A:

The SIM900A GSM module provides cellular communication capability for transmitting accident alerts. The module operates over the GSM network and supports SMS communication through AT command interface.

After receiving the accident detection signal and GPS coordinates, the ESP32 sends AT commands to the GSM module to transmit an SMS alert containing Accident notification message, Latitude and longitude location coordinates, Timestamp information (optional)

The GSM communication system ensures that emergency responders receive real-time accident notifications.

F. User Interface Module — 16×2 LCD Display:

A 16×2 alphanumeric LCD display is used for real-time monitoring of system operation. The display communicates with the ESP32 using an I²C interface module, reducing the number of required microcontroller pins.

The LCD display shows important information such as System initialization status, GPS connectivity status, Vibration sensor readings ,Accident alert transmission confirmation

This user interface assists in monitoring system functionality during installation and maintenance.

G. Self-Powered Energy Subsystem:

The proposed accident alert beacon is designed to operate using a self-powered energy source to enable deployment in remote

roadside environments. The system can utilize solar panels, rechargeable batteries, or other renewable power sources to maintain continuous operation.

The power subsystem includes voltage regulation circuits to provide stable power supply to the ESP32, GSM module, GPS module, and LCD display. This autonomous power architecture ensures reliable system operation without dependence on external electrical infrastructure.

H. Mechanical Deployment and Installation:

The roadside accident alert beacon is designed for installation at accident-prone locations such as highways, sharp turns, and remote road segments. The system components are enclosed within a protective housing to withstand environmental conditions including dust, vibration, and temperature variations.

The vibration sensor is positioned in such a way that it can detect strong impact vibrations transmitted through the surrounding environment. The compact and modular design enables easy installation and maintenance of the system.

IV. SOFTWARE DESIGN AND SYSTEM OPERATION

The software architecture of the proposed system is implemented using the Arduino development environment with embedded C/C++ programming for the ESP32 microcontroller. The software controls sensor monitoring, accident detection logic, location acquisition, and emergency alert transmission. During system initialization, all hardware modules including the LCD display, vibration sensor, GPS module, and GSM module are configured and verified for proper operation. The ESP32 continuously reads the vibration sensor output and converts the detected signal into digital values. These values are compared with a predefined threshold level stored in the program memory. Under normal conditions, the vibration values remain within the safe range and the system remains in monitoring mode. If a sudden impact occurs and the vibration value exceeds the threshold limit, the microcontroller interprets the event as a potential accident.

Once an accident event is detected, the ESP32 activates the alert sequence. The GPS module is accessed through the UART communication interface to obtain the current latitude and longitude coordinates of the accident location. The microcontroller parses the GPS data and extracts the required location information. After retrieving the location data, the ESP32 generates an emergency alert message containing the accident notification and geographic coordinates. This message is transmitted to predefined mobile numbers using the GSM module through AT command communication. The alert message allows emergency responders to quickly identify the accident location and initiate rescue operations.

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Simultaneously, the 16×2 LCD display updates the system status by displaying information such as vibration detection status, GPS connectivity, and alert transmission confirmation. Once the message is successfully transmitted, the system returns to monitoring mode and continues observing sensor inputs for further events.

The software design ensures real-time accident detection, reliable communication between hardware modules, and minimal response delay, making the system suitable for deployment in roadside accident monitoring applications.

V. EXPERIMENTAL RESULTS AND SYSTEM EVALUATION

The proposed accident alert system was tested under controlled experimental conditions to evaluate its performance and reliability. The vibration sensor was subjected to simulated impact conditions to replicate collision events.The system successfully detected strong vibration signals exceeding the predefined threshold value and triggered the accident alert mechanism. The ESP32 microcontroller processed the sensor signals and activated the GPS module to obtain location coordinates. The GPS module provided accurate latitude and longitude information, which was successfully transmitted through the GSM module as an SMS alert message. The received message contained both accident notification and location coordinates.

The LCD display continuously updated the system status, showing sensor readings, GPS connectivity status, and alert transmission confirmation. The experimental results demonstrate that the system can effectively detect accident events and deliver emergency alerts with minimal delay.

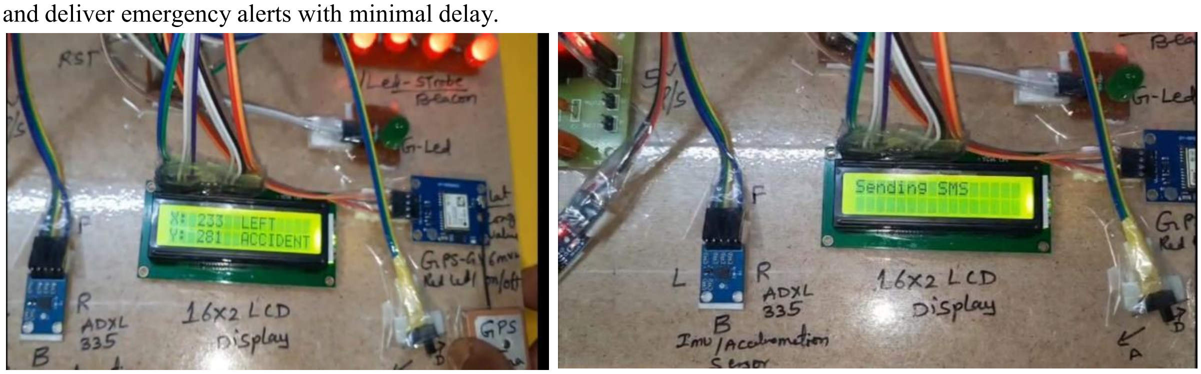

Fig 1- Alert System is Sending SMS to Registered Number.

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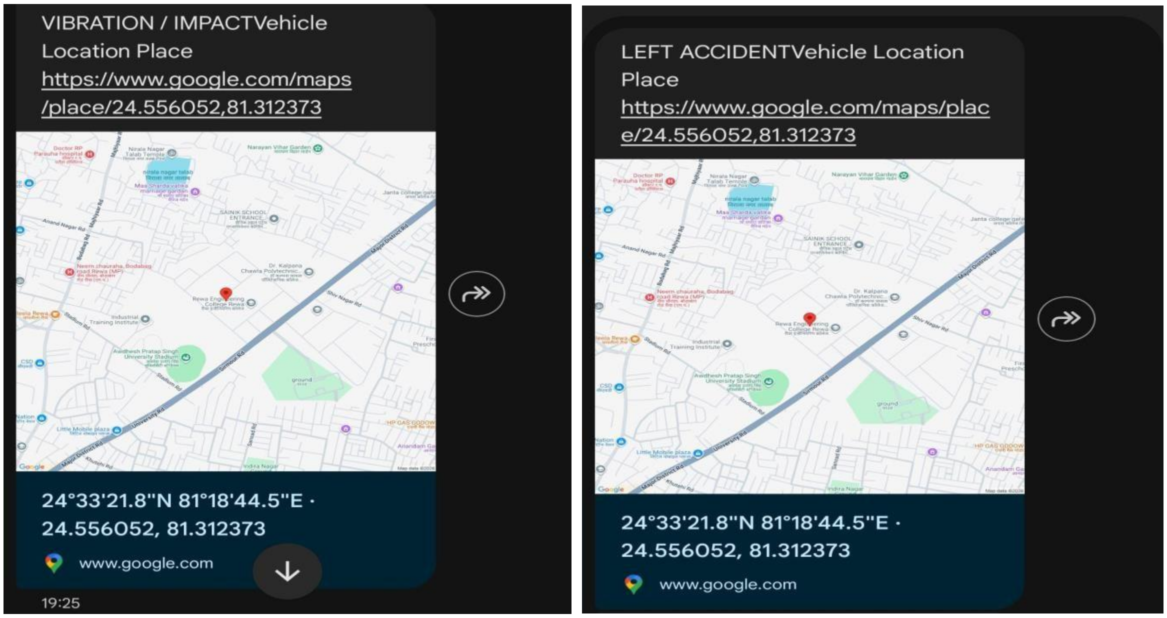

Fig-2: The Registered Number has received the SMS of Accident.

VI. DISCUSSION

The development of a Self-Powered Roadside Accident Alert Beacon provides an effective technological solution for improving road safety and emergency response systems. The proposed system demonstrates how embedded systems and wireless communication technologies can be integrated to automatically detect accident events and notify emergency services with minimal human intervention. The experimental results indicate that the vibration sensor can successfully detect sudden impact events associated with vehicle collisions. The ESP32 microcontroller efficiently processes the sensor signals and activates the alert mechanism when the predefined threshold value is exceeded. The GPS module provides accurate location coordinates, enabling precise identification of accident locations. The GSM communication module ensures reliable transmission of emergency alert messages to predefined contacts.

One of the major advantages of the proposed system is its independent roadside deployment capability. Unlike vehicle-based accident detection systems, the proposed beacon does not rely on the electronic systems of individual vehicles. This makes it suitable for installation at accident-prone areas such as highways, sharp turns, and remote road segments where accidents

frequently occur. The system also demonstrates cost-effectiveness and ease of implementation. The use of low-cost embedded components such as ESP32, vibration sensors, and GSM modules makes the system economically feasible for large-scale

deployment. Additionally, the integration of a self-powered energy subsystem allows continuous operation in remote environments where conventional power infrastructure may not be available. However, certain limitations must be considered. Environmental vibrations caused by heavy vehicles or construction activities may occasionally produce false triggers if the threshold value is not properly calibrated. Future improvements may involve the use of advanced sensor fusion techniques or machine learning algorithms to improve accident detection accuracy and reduce false alerts. Integration with IoT cloud platforms, real-time traffic monitoring systems, and smart city infrastructure could further enhance the functionality of the system. Such improvements would enable centralized monitoring and data analysis of accident events across large geographic regions.

VII. CONCLUSION

This paper presented the design and implementation of a Self-Powered Roadside Accident Alert Beacon capable of automatically detecting accident events and transmitting emergency alerts with accurate location information. The proposed system integrates vibration sensing, GPS-based location tracking, and GSM communication technologies to provide a reliable accident detection and notification mechanism. The ESP32 microcontroller serves as the central control unit, continuously monitoring vibration sensor data and processing accident detection logic. When a sudden impact exceeding the predefined threshold value is detected, the system retrieves the accident location using the GPS module and transmits an emergency alert message through the GSM module. The 16×2 LCD display provides real-time system monitoring and operational feedback.

Experimental testing confirmed that the system can effectively detect accident events and successfully transmit location-based emergency alerts with minimal delay. The proposed solution offers several advantages including automatic accident detection, reduced emergency response time, low implementation cost, and autonomous operation in remote roadside environments. The deployment of such systems at accident-prone locations can significantly improve road safety and assist emergency responders in providing timely medical assistance to accident victims. In future work, the system can be enhanced by integrating IoT connectivity, renewable energy sources such as solar panels, and advanced accident detection algorithms to further improve reliability and scalability

The proposed accident alert beacon represents a promising step toward the development of intelligent transportation safety systems that can help reduce fatalities and improve emergency response efficiency.

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