

Accident Detection and Alerting Using Embedded System

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Abstract: Road accidents are among the leading causes of fatalities worldwide, often exacerbated by delayed emergency response and a lack of real-time information. This paper presents the design and implementation of an embedded accident detection and alerting system designed to reduce response times and enhance road safety. The proposed system integrates multiple sensors, an accelerometer (ADXL335) for detecting sudden motion changes, a vibration sensor (SW420) for sensing impact, and an ultrasonic sensor (HC-SR04) for collision confirmation. These sensors are interfaced with an Arduino Uno microcontroller, which processes the sensor data to accurately identify accidents while minimizing false alarms. Upon accident detection, the system utilizes a GSM module (SIM800L) to transmit an alert message containing the geographical coordinates obtained from a GPS module (NEO-6M) to predefined emergency contacts, including police stations and medical facilities. Both simulation and hardware implementation validate the system's effectiveness in real-time accident detection, location tracking, and rapid alert dissemination. Experimental results demonstrate improved accuracy and reduced response time, thereby enhancing the likelihood of timely medical intervention. The proposed system is cost-effective, portable, and energy-efficient, making it adaptable across different types of vehicles. Potential future enhancements include integration of wireless imaging for accident scene capture and cloud-based storage for data analysis and intelligent transportation systems.

Keywords: Accident detection, Embedded system, Arduino Uno, GPS, GSM

I. INTRODUCTION

Road accidents are a major global concern, contributing significantly to economic loss, property damage, and human fatalities. Studies indicate that more than 50% of accidents are caused by negligent driving, highlighting the urgent need for improved monitoring and safety measures. Research has shown that even an additional 0.5 seconds of driver reaction time can reduce collisions by nearly 45%, underscoring the importance of timely detection and response mechanisms. methods, accelerometer-based systems (g-sensors) are widely adopted due to their affordability and ability to measure motion along multiple axes with high precision. In addition, advancements in autonomous and intelligent systems have integrated novel sensors for object recognition, navigation, and situational awareness, aiming to minimize accident-related casualties. Motion sensors combined with a data fusion algorithm that incorporating acceleration, deceleration, and tilt angle that have shown promising results in improving detection accuracy while filtering out background noise such as engine vibrations.

The European Union's E-call system is an example of a practical solution that reduces the response time between an accident and the arrival of emergency services by nearly 50%. Inspired by such approaches, this paper proposes a novel embedded system for vehicle crash detection. The system employs an accelerometer, vibration sensor, and ultrasonic sensor to detect accidents, while a microcontroller processes the data to minimize false alarms. Upon detection, the system transmits the accident location via GPS and GSM modules to predefined emergency contacts.

Accident detection systems form a crucial component of the broader Intelligent Transportation System (ITS) framework. Beyond enhancing emergency response, they can reduce congestion caused by accidents and provide



valuable data for traffic management and urban planning. With continuous advancements in embedded technologies, these systems are expected to become increasingly reliable, efficient, and capable of saving lives.

Ease of Use

Motivation

Injuries and fatalities resulting from vehicle crashes pose significant economic and social burdens, with over 50% attributed to negligent driving. To enhance road safety, nations worldwide have been investing in car crash avoidance technology. Studies indicate that providing drivers with an additional 0.5 seconds of reaction time can decrease collisions by 45%. Consequently, modern vehicles are equipped with various measurement and alert systems to mitigate risks. Crash detection in vehicles can be accomplished through multiple methods, with g-sensors (accelerometers) being a popular choice due to their affordability and ability to precisely measure changes in x, y, and z values. Today, advancing autonomous systems to assist humans in daily tasks stands as a pivotal challenge in computer science. Autonomous driving systems exemplify this pursuit, aiming to curb traffic accident fatalities. Recent years have witnessed the integration of novel sensors for tasks like object recognition, navigation, and manipulation. The motion sensor method uses a complex motion processor to provide very accurate data and, if used near the engine, can also filter out vibrations [1-10]. Automotive sensors are used to reduce vibration and made readings very accurate. Algorithms that use data fusion between acceleration, deceleration, and tilt angles have a great success rate. Collision detection is a very important feature for motorcycle occupants and is used by the E-call system, which can reduce the time between an accident and emergency service arrival by 50%. In this paper, a novel embedded system for vehicle crash detection is presented. The system detects the distance between the vehicle and the vehicle front (object) and uses data from the acceleration sensor and the vibration sensor. Moreover, by considering the situation over time, we devised a shock event algorithm that is more suitable for the real world. Accident detection systems are a crucial part of the broader Intelligent Transportation System (ITS) framework, which aims to create safer, more efficient, and more reliable transportation networks. By enabling faster emergency responses, reducing congestion caused by accidents, and potentially providing valuable data for traffic management and urban planning, these systems represent a significant advancement in road safety technology. In summary, the development and implementation of accident detection systems are essential for enhancing road safety and mitigating the consequences of traffic accidents. As technology continues to evolve, these systems will likely become more sophisticated, further improving their effectiveness and reliability in saving lives and reducing injuries on the roads.

Background

Currently, traffic accidents pose a significant global concern, leading to numerous injuries and fatalities, highlighting the dire state of road safety worldwide. Statistical forecasts on traffic-related deaths consistently point to a common issue: the lack of timely provision of first aid, often resulting from delays in accident information reaching emergency services or medical facilities. Before conceptualizing the Accident Alert System, extensive analysis was conducted on a variety of patents. It helped us to understand the interfacing of various components used in the project, such as GSM and GPS modems, and also the practical implementation of such projects in real life. Through analyzing these research papers, we gained an understanding of the contemporary technologies in the accident notification system domain, enabling the exploration of more efficient and straightforward alternatives to update these systems. In conclusion, the development of accident detection systems has evolved from simple mechanical sensors to complex, AI-driven networks capable of real-time data analysis and communication. These systems are crucial for improving road safety, reducing response times, and ultimately saving lives. As technology continues to advance, we can expect even greater enhancements in the accuracy, reliability, and integration of accident detection systems into the broader ITS framework. Accident detection systems are crucial in enhancing road safety by providing immediate alerts and accurate location information during emergencies. The ADXL335 accelerometer is a pivotal component in such systems, capable of detecting sudden changes in motion indicative of a collision. When integrated with a GPS module, the system can pinpoint the exact location of the accident. Additionally, a GSM module is employed to communicate this data to emergency services or predetermined contacts. Research in this field has focused on the reliability and accuracy of



these sensors in detecting accidents, minimizing false positives, and ensuring the timely transmission of information. Studies have shown that combining these technologies significantly reduces the response time in emergencies, potentially saving lives by enabling quicker medical intervention. The integration of ADXL 335, GPS, and GSM 2 modules in accident detection systems exemplifies a synergistic approach, leveraging the strengths of each technology to create a comprehensive and efficient solution for real-time accident reporting.

II. LITERATURE REVIEW

- 1) Zaldivar, J., Calafate, C. T., Cano, J. C., & Manzoni, P. (2011). Accident detection in vehicular networks via OBD-II devices and Android smartphones. The authors have developed a car accident detection and notification system that integrates smartphones with vehicles via the second generation of On-Board-Unit (OBD-II) interface, enabling smart vehicle modelling. Their Android application sends SMS alerts in a predefined format with accident data and can also trigger automatic emergency calls, which help to find the location of an accident.
- 2) Sontakke, S. R., & Gawande, A. (2013). Crash Notification System for Portable Devices. International Journal of Advanced Computer Technology, 2(3), 33-38. The prospect of creating an automatic crash detection and notification service for portable devices, such as smartphones, has been investigated in the E-call system. This system has made use of the cellular network to facilitate communication between the Server Center and the portable device. The primary drawback of the technology is that the E-call system uses the accelerometer sensor included in smartphones as a crash sensor, which can lead to a large number of false positives while the user is not inside the car.
- 3) Ali, H. M., & Alwan, Z. S. (2017). Car accident detection and notification system using smartphones. LAP LAMBERT Academic Publishing Saarbrucken. The OBD-II standard is mandatory in the U.S. and Europe; its application is limited in other regions, and system maintenance or upgrades can be costly. Another explored solution is the E-call system, which investigates implementing automatic crash detection and notification services for smartphones. This system utilizes the cellular network to communicate between portable devices and a central server. However, it relies on the smartphone's built-in accelerometer sensor, leading to a high rate of false positives when users are not in their vehicles. In Iraq, researchers have developed a system utilizing accelerometers, GPS, and microphones to detect accidents and notify emergency contacts and responders via SMS and a web server. However, responders must manually check the web server for accident notifications, and the system lacks features for individual responders to track victims' locations or send alerts to the nearest emergency centers.

III. ABBREVIATIONS AND ACRONYMS

GSM	Global System for Mobile Communication
GPS	Global Positioning System
SMS	Short Message Service
AC	Alternating Current
DC	Direct Current
IC	Integrated Circuit
VCC	Voltage at the common collector
GND	Ground
EEPROM	Electrically Erasable Programmable Read-Only Memory
TX	Transmitter
RX	Receiver
BSS	Base Station System
BPS	Bits Per Second
MEMS	Microelectromechanical systems
SIM	Subscriber Identity Module



IV. METHODOLOGY

IV.1 Detection and Alerting Approach

The proposed system employs a multi-sensor embedded architecture to detect vehicle collisions in real time. An ADXL335 three-axis accelerometer continuously measures acceleration along the X, Y, and Z axes, while an SW-420 vibration sensor provides a digital shock indicator. An HCSR04 ultrasonic range sensor monitors forward obstacle distance. The Arduino Uno microcontroller reads these sensors at a fixed sampling interval (e.g., every 10 ms). After each sample, the accelerometer readings are combined into a resultant acceleration magnitude. If this magnitude exceeds a predefined collision threshold (on the order of 3g), the system then checks the vibration output. If the vibration sensor's digital output also exceeds its threshold (e.g., 1000 mg for simulation), the system finally evaluates the ultrasonic reading. Only when the ultrasonic sensor detects an object within a critical range (about 5 cm) and both accelerometer and vibration thresholds are met, the Arduino concludes that a collision has occurred. Requiring all three conditions concurrently significantly reduces false triggers. In this way, the system combines acceleration, shock, and proximity data to robustly distinguish accidents from normal driving.

IV.2 Waterfall Development Model

The project was executed under a classical Waterfall process model. The work was divided into sequential phases, each completed before moving to the next. First, Project Planning identified the accident-detection problem and defined objectives. Next, Information Gathering involved surveying literature on sensor-based collision detection. During Requirements Analysis, the necessary hardware (Arduino Uno, GSM/GPS modules, ADXL335 accelerometer, SW-420 vibration sensor, HC-SR04 ultrasonic sensor) and functional specifications were determined. Concurrently, Skill Acquisition ensured proficiency in C/C++ programming and Arduino interfacing. In the Design and Development phase, the system architecture and control algorithms were implemented in Arduino C/C++ (using libraries like SoftwareSerial for GPS/GSM communications). Testing and Debugging, then validated each module: accelerometer calibration, threshold logic, GPS/GSM connectivity, etc., with iterative fixes. Finally, a Maintenance plan was outlined to handle future updates and repairs, ensuring long-term reliability. This disciplined waterfall approach ensured systematic progress and thorough verification at each step [11-50].

IV. 3 Hardware and Software Components

The core hardware consists of an Arduino Uno microcontroller interfaced with a SIM800L GSM module, a NEO-6M GPS receiver, an ADXL335 3-axis accelerometer, an HC-SR04 ultrasonic sensor, and an SW-420 vibration sensor. The ADXL335's X, Y, and Z analog outputs are connected to the Arduino's A0, A1, and A2 inputs. The ultrasonic sensor's TRIG and ECHO pins are wired to digital pins D10 and D11, respectively, powered by 5V. The SW420 vibration sensor's digital output goes to pin D12. The GPS and GSM modules communicate via serial: each is connected using the Arduino SoftwareSerial library (e.g., GPS TX/RX on D8/D9, GSM TX/RX on D2/D3). Power supplies are provided as appropriate (5V for Arduino and sensors, 3.7V for the GSM). The Arduino firmware is written in C/C++ using the Arduino IDE; it leverages the SoftwareSerial library for sensor communication and standard libraries for analog/digital I/O. This combination of components provides real-time sensing and wireless connectivity in a compact embedded system.



IV.4 Flowchart with Explanation

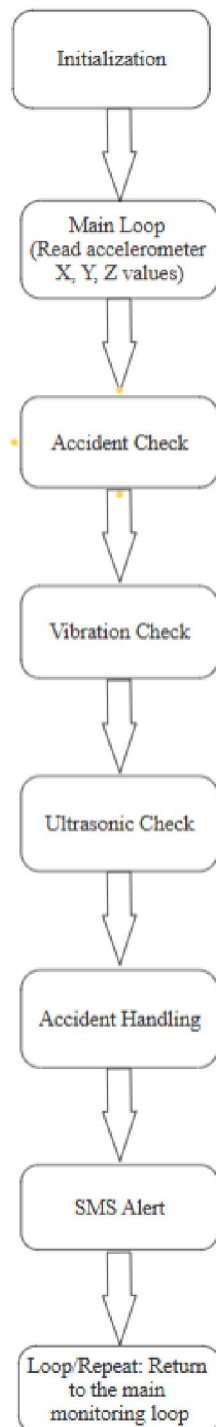


Fig. 1- Flowchart of Implementation Process



IV.4 Explanation

At the initialization stage, the system configures and activates all necessary hardware components, which include the microcontroller, accelerometer, vibration sensor, ultrasonic sensor, and GSM module. In addition, the required software libraries are loaded, and threshold values for accident detection are carefully calibrated. This initial setup ensures that the system operates with optimized parameters for accurate monitoring and reliable decision-making. Once initialization is complete, the system transitions into its main operational loop, where it continuously records accelerometer readings along the X, Y, and Z axes. These measurements are crucial for identifying irregularities in the vehicle's movement, such as sudden impacts, abnormal tilts, or deviations from normal driving patterns.

When the accelerometer detects acceleration levels that exceed the predefined threshold, the system advances to an accident verification phase to minimize false positives. In this phase, the vibration sensor is employed to confirm the presence of strong physical shocks or vibrations typically associated with a collision. Following this, the ultrasonic sensor is activated to analyze the vehicle's immediate surroundings. This sensor provides additional confirmation by determining whether the vehicle has come to an abrupt halt or has collided with an external obstacle. The layered approach involving multiple sensors enhances the reliability of the accident detection process and reduces the probability of erroneous alerts caused by minor disturbances.

Upon successful confirmation of an accident, the system enters the accident handling phase. At this point, an emergency notification is generated, which includes critical information such as the occurrence of the accident and the vehicle's real-time location. The location data, retrieved from an integrated GPS module, is embedded within the alert to enable prompt assistance. The GSM module then transmits this message to pre-registered emergency contacts, which may include family members, local hospitals, and rescue services. This ensures that essential stakeholders are informed immediately, thereby facilitating timely intervention. After the successful dispatch of the emergency alert, the system resets to its monitoring state and resumes continuous tracking, thereby maintaining uninterrupted surveillance for subsequent incidents.

The system ensures reliable accident detection by integrating accelerometer, vibration, and ultrasonic sensors with GPS and GSM modules. Verified incidents trigger automated emergency alerts containing real-time location, enabling timely assistance. After alert transmission, the system resets to monitoring mode, ensuring continuous operation and minimizing false alarms for effective accident management.

IV.5 Block diagram of hardware Implementation

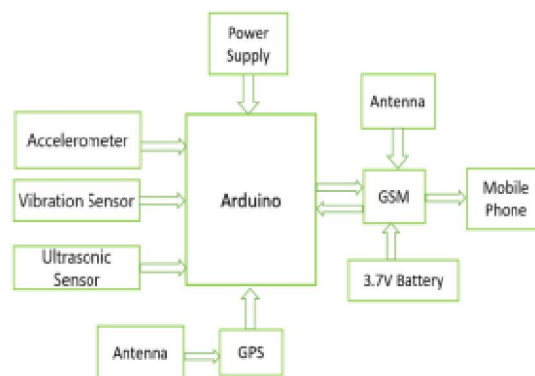


Fig. 2. Block diagram of vehicle accident detection

As shown in Fig.2, the Arduino board is powered either through a laptop USB port or an external power bank. Since the Arduino is equipped with an onboard voltage regulator, it is capable of maintaining stable voltage levels even in the presence of input fluctuations. Three sensors are interfaced with the Arduino for accident detection. An accelerometer is



utilized to detect sudden variations in speed, while a vibration sensor identifies external impacts, and an ultrasonic sensor assists in collision detection. All three sensors are powered directly from the Arduino, thereby simplifying the overall power management process.

To enable location tracking, the GPS module is interfaced with the Arduino through an external antenna, which enhances satellite signal reception and ensures accurate localization of the accident site. In addition, a GSM module is connected to the Arduino for communication purposes. This module is also equipped with an antenna to ensure reliable network connectivity for transmitting GPS coordinates. As the GSM module requires a higher operating current of approximately 2 A, it is powered separately using an external 3.7 V lithium-ion battery.

This integrated hardware configuration ensures that the accident detection and alerting system operates efficiently and reliably across diverse environments, providing accurate location information and timely alerts during critical situations.

IV.6 System description

The System works in three phases:

Accident Detection:

The accident detection phase relies on three primary sensors: an accelerometer, a vibration sensor, and an ultrasonic sensor.

The accelerometer monitors the orientation of the vehicle along the X, Y, and Z axes. Under normal conditions, the reference angle is initialized at zero degrees, with possible variations up to 360°. A crash is detected when the variation in orientation exceeds a predefined threshold, typically set at 320° for the X and Y axes. The detection condition is expressed as:

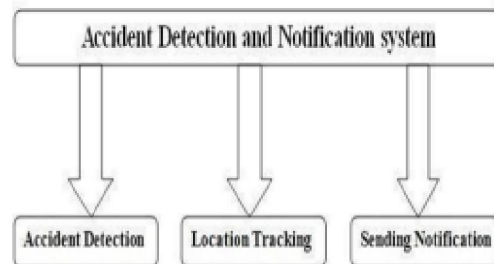


Fig.3 System description model

$|x_2 - x_1| > \text{X-axis threshold}$,

$|y_2 - y_1| > \text{Y-axis threshold}$,

$|z_2 - z_1| > \text{Z-axis threshold}$,

If the change in acceleration along any axis exceeds 3g (29.4 m/s²), the event is classified as an accident. For simulation, the accelerometer threshold is calibrated to 20 mg. The vibration sensor complements this process by detecting sudden shocks generated during collisions. When the vibration intensity exceeds a set threshold of 1000 mg, the sensor outputs a signal to the microcontroller, indicating a possible crash event. The ultrasonic sensor, mounted on the vehicle, continuously monitors obstacles within a 5 cm range. If an object is detected within this range, and the accelerometer and vibration thresholds are simultaneously exceeded, the system confirms the occurrence of an accident and triggers further actions.

Location Tracking:

Once an accident is confirmed, the GPS module is activated to acquire the vehicle's geographic location. The module determines the accident site by receiving signals from multiple satellites and calculating parameters such as latitude, longitude, altitude, and time. These coordinates are transmitted to the Arduino microcontroller for processing.



Sending Notification:

As soon as the GPS provides the accident location coordinates, the GSM module sends text messages to the police control room and the hospital. These messages included a link to a map that shows the precise latitude and longitude of the accident site. Concurrently, a message with a link to a Google Maps is sent to the closest police station, informing it of the accident. With the use of this thorough information, the ambulance can quickly find the quickest path to the scene of the accident, cutting down on response time and improving the likelihood that the victim will survive.

IV.7 Hardware Implementation

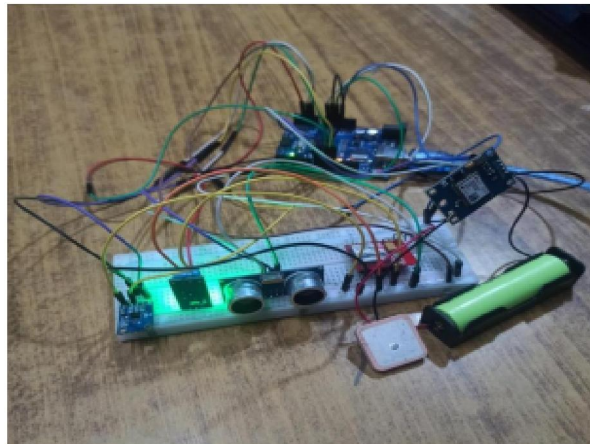


Fig.4. Real-time hardware implementation

After successful simulation and testing, the proposed accident detection and alerting system was implemented in hardware using an Arduino Uno microcontroller. The developed code (Code 2, Appendix) was uploaded to the Arduino to integrate the required sensors and communication modules. The hardware consists of three major parts: accident detection, location tracking, and alert transmission.

For accident detection, the ADXL335 accelerometer was used to monitor the acceleration along the X, Y, and Z axes. Its three analog outputs were connected to the Arduino's analog pins A1, A2, and A3, allowing continuous measurement of vehicle orientation and motion. Any sudden or abnormal deviation beyond a predefined threshold indicated a possible accident. In addition, the SW-420 vibration sensor was connected to the Arduino through its digital output (DO) pin at D12. The sensor generated a LOW signal when vibration or shock was detected, thereby confirming impact events. To further enhance detection, an HC-SR04 ultrasonic sensor was used for obstacle proximity measurement. Its Trig and Echo pins were connected to digital pins D10 and D11 of the Arduino, and by measuring the pulse duration, the system calculated the distance to nearby objects. All these sensors were powered through the Arduino's 5V and ground pins.

For location tracking, a NEO-6M GPS module was integrated with the system. The Tx pin of the GPS module transmitted location data in the form of NMEA sentences containing latitude and longitude, while the Rx pin allowed configuration commands to be sent from the Arduino. The module was powered using the 3.3 V supply of the Arduino. This ensured accurate real-time tracking of the vehicle's position during accidents.

For alert transmission, the SIM800L GSM module was employed to send SMS notifications. Its Tx and Rx pins were interfaced with Arduino digital pins 2 and 3, respectively, enabling two-way communication. The Tx pin of the GSM module transmitted responses such as AT command outputs and incoming SMS data, while the Rx pin received AT commands from the Arduino. Using this configuration, the system was able to automatically send SMS alerts containing accident and location details to predefined emergency contacts.

V. RESULTS AND DISCUSSION

The results demonstrate the effectiveness of the automated accident detection and alerting system in accurately recognizing collisions and promptly notifying nearby law enforcement agencies and emergency medical facilities. This timely dissemination of information enables immediate medical assistance to accident victims, thereby reducing injury severity and improving survival rates. The system consistently achieved high accuracy in detecting crashes, supported by reliable location tracking through the GPS module and efficient communication via the GSM module. The alert dissemination process was both timely and dependable, ensuring that critical information reached the intended recipients without delay. Additionally, the system exhibited stability and robustness during testing, confirming its potential for real-world deployment in diverse vehicular environments.

Several advantages contribute to the practicality of the system. The design is highly portable and user-friendly, with a simple architecture that relies on readily available components, making it both cost-effective and easy to manufacture. Its portability offers versatile placement options, while the integration of wireless communication ensures faster data transmission. Furthermore, the system requires minimal maintenance and repair, operates with low power consumption, and maintains an efficient and economical design. Beyond accident detection, the system offers wide-ranging applications. It can be deployed across multiple vehicle categories to provide real-time accident detection and automated alerts to nearby emergency responders. In addition, the GPS-enabled tracking capability allows the system to be utilized for monitoring stolen vehicles, further extending its utility in improving road safety and enhancing vehicular security. With further refinements, the system holds significant promise for reducing emergency response times and contributing to safer transportation infrastructure.

VI. CONCLUSION

In Conclusion, the presented a vehicle accident detection and alerting system that integrates GPS tracking and GSM-based communication to provide real-time emergency notifications. The system accurately identifies collision events using onboard sensors and transmits precise location data to predefined contacts via SMS, ensuring timely intervention by law enforcement and medical services. Experimental validation demonstrated the system's reliability, robustness, and efficiency in both detection and communication processes. The architecture is lightweight, cost-effective, and energy-efficient, making it suitable for deployment across diverse vehicle types. Beyond accident detection, the modular design allows for future enhancements, including cloud-based monitoring, IoT integration, and stolen vehicle tracking. Overall, the proposed system offers a practical and scalable solution to improve road safety, minimize emergency response times, and reduce accident-related fatalities.

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