

Smart Black-Box Architecture For Autonomous Accident Detection And Geolocation

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Abstract

This research work proposes an intelligent black-box design framework for accident prevention, detection and geolocation through the integration of heterogeneous sensing and communication devices into the embedded ATmega platform. The proposed system combines an MQ3 alcohol sensing device, seat belt sensor, eye blink sensor, DHT11 temperature sensor, ultrasonic sensor, and ADXL335 accelerometer. Condition based control actions are employed to stop the prototype engine if the rider consumed alcohol, warning generation for long eye closure and high temperature, and reduces prototype engine speed when close vehicle proximity is detected. In case of an accident, the accelerator triggers the emergency response process by sending the user's location acquisition using GPS coordinates and transmission of latitude and longitude along with the Google Maps link to emergency contacts through GSM. Stepper motor helps to illustrate the control responses. The presented prototype implementation through serial monitor observations and emergency message transmission confirms the sensing, decision-making, accident detection, location acquisition, and notification process proves the effectiveness of the proposed design in real-time scenarios.

Keywords: Smart Black-Box, Autonomous Accident Detection, Driver-State Monitoring, Vehicle Proximity Sensing, Embedded Safety Control, GPS-GSM Geolocation, Emergency Alert Communication

1. Introduction

Road accidents are influenced by various factors such as impairment of drivers, drowsiness, improper vehicle proximity, abnormalities in the condition of vehicles, and accidents that happen suddenly. Traditional safety systems often address these conditions independently, limiting the ability to provide coordinated prevention and immediate emergency response. Automated accident detection using sensors and IoT systems have shown their capability in detecting accidents and providing alerts [1], [8].

The GPS and GSM systems play a major role in enabling automatic transmission of accident related data to the emergency contacts without necessarily relying on manual reporting [3], [6]. Nevertheless, the incorporation of driver condition monitoring, vehicle condition monitoring, proximity monitoring, collision detection, and emergency location within an embedded system is essential for implementation.

This research presents an intelligent black box structure for automatic accident detection and geolocation using an ATmega microcontroller and several sensor blocks. The system consists of alcohol, eye-blink, seat belt, temperature, ultrasonic, and accelerometer sensors for preventative and accident sensing purposes. A stepper motor has been employed as a prototype engine, whereas GPS and GSM have been employed for location sensing and communication purposes. The proposed architecture enables condition-based vehicle control, warning for the driver, detection of accidents, and automatic transmission of location data to emergency contacts.

2. Literature Survey

2.1 Sensor-Based Accident Detection and Prevention

Many research works have been initiated for analyzing the use of sensors in preventing and detecting accidents. Sankpal [2] proposed an accident prevention method through the use of infrared transmission for detecting the close-proximity vehicles and preventing accidents. Kalyani et al. [7] designed a system for detecting and triggering alerts about accidents. Furthermore, Patil and Pardeshi [10] have used embedded sensors, Arduino, GSM and GPS in order to integrate the detection, prevention and reporting of accidents. The above-mentioned examples prove the efficiency of embedded sensing in the identification of potentially hazardous states of vehicles, yet the mentioned systems are dependent on some particular accident-related parameter only.

2.2 IoT-Based Vehicle Accident Detection

IoT-based architectures have been increasingly adopted for automated accident monitoring and emergency communication. Aslam et al. [1] proposed an IoT-based automatic vehicle accident detection system with visual situation reporting to support post-accident assessment. Tasgaonkar et al. [8] developed an IoT-based framework for vehicle accident detection in smart-city environments, integrating sensing, communication, and location-based services. Sowah et al. [9] have developed an IoT-enabled automatic vehicle accident detection system that can transmit information about the accidents without requiring any manual intervention. All the above works indicate the application possibilities of IoT for real-time accident monitoring; nevertheless, the integration of preventive monitoring of drivers/vehicle conditions in the same embedded architecture remains limited.

2.3 GPS and GSM-Based Accident Alert and Geolocation

GPS and GSM systems have been extensively used to send accident location information to emergency contacts. A system for accident detection and location by utilizing GSM and GPS for communication of information related to accidents was proposed by Vijayakumar et al. [3]. An accident detection and alerting system on the basis of smart phones which uses motion and location information of vehicles was designed by Faiz et al. [5]. Gupta et al. [6] investigated a detection and alarm system based on motion sensing and GPS for emergency assistance. Such systems show the need for automated location sensing post-accidents; nonetheless, the dependence on communications-enabled devices or sensor sensing limitations may limit the overall effectiveness of the safety system.

2.4 Driver Monitoring and Intelligent Accident Prevention

Driver state monitoring can also be used for accident prevention due to human factors. According to Kailasam et al., [4] an accident prevention system can be developed based on face recognition to monitor driver related issues. This is yet another way of ensuring safety as opposed to just focusing on movement of the car. Nevertheless, camera-based surveillance alone is not enough to detect accidents or assess the condition of vehicles. From the reviewed researches, there is a need for an architecture that integrates driver state monitoring, vehicle condition sensing, proximity sensing, accident sensing, GPS localization, and GSM emergency communication. This is taken into consideration in the proposed architecture through the

integration of alcohol sensors, eye-blink sensors, seat belt sensors, DHT11 temperature sensors, ultrasonic sensors, and ADXL335 accelerometers.

3. Proposed Methodology

3.1 System Architecture and Hardware Configuration

The proposed system is developed as an embedded vehicular safety system comprising accident prevention, driver status monitoring, vehicle status monitoring, accident detection, and emergency communication. The processor used in the design is an ATmega microcontroller, which receives signals from the sensor modules and controls the warning, engine, and communication systems. The hardware architecture consists of MQ3 alcohol sensor, blink detection sensor, seat belt sensor, DHT11 temperature sensor, ultrasonic sensor, ADXL335 accelerometer, GPS module, GSM module, and a stepper motor which serves as the prototype engine. The overall operating procedure of the proposed system is shown in Figure 1.

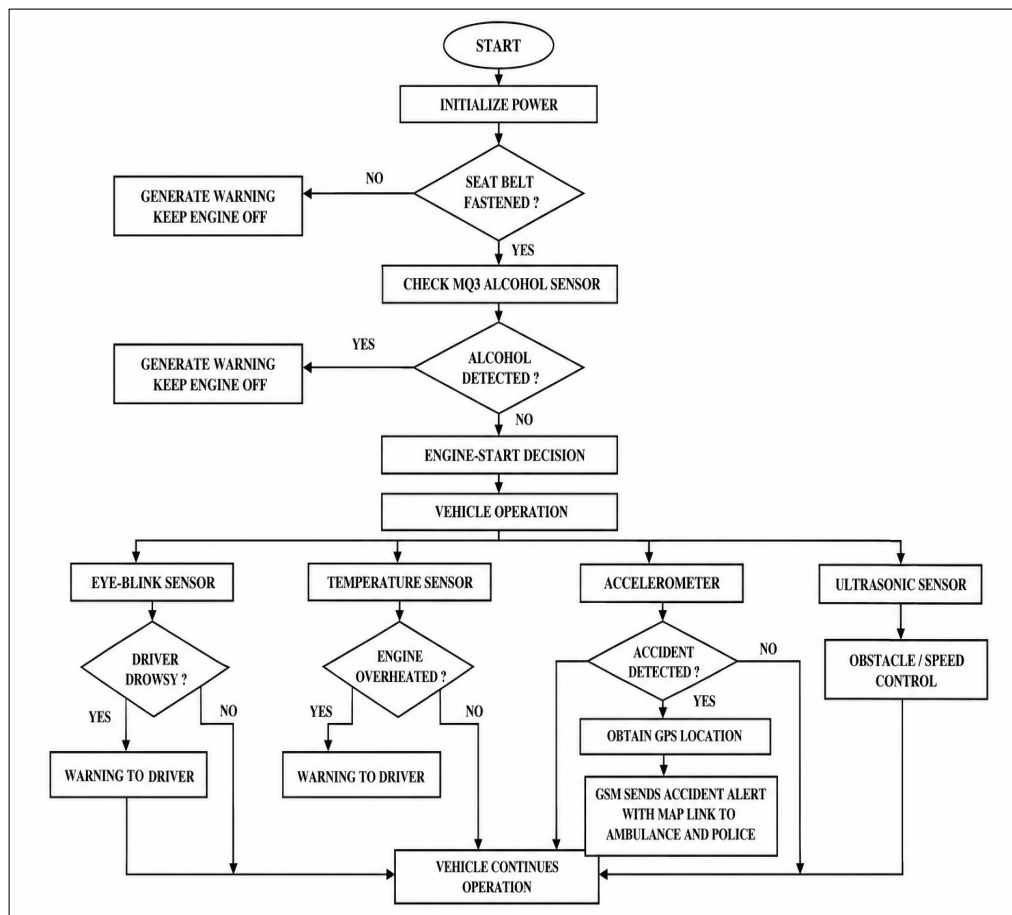


Figure 1. Operational flowchart of the proposed accident detection and geolocation system

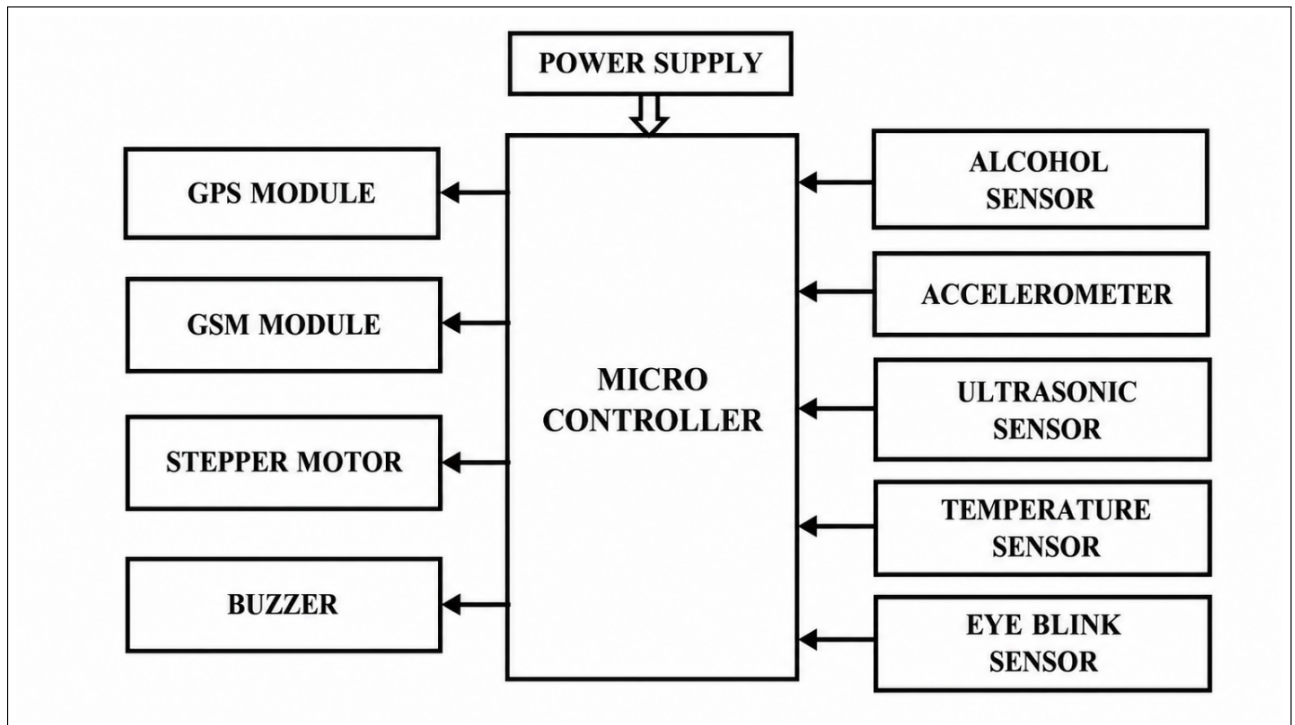


Figure 2. Functional block diagram of the proposed system

Functional connection between the sensing, processing, actuation, and communication components is depicted in Figure 2. The signals from the sensors are fed into the ATmega controller for further decisions. Depending on the recognized state, the controller will produce the required action in the form of restrictions in engine activity, alerts or the control over the engine of the prototype. If the accidental state occurs, GPS and GSM modules are employed for location determination and alarming purposes, respectively. The stepper motor serves as the prototype of the vehicle engine.

3.2 Driver Safety Monitoring

The system will monitor the state of the driver by using seatbelt sensors, alcohol detectors, and eye blinking sensors. Before the prototype engine can run, the seatbelt sensor will be tested to ensure that the driver has buckled the seat belt. The prototype engine will only function when there is satisfaction of the seatbelt state.

MQ3 alcohol sensor is tested prior to the operation of the prototype engine. Sensor output is analyzed based on the set detection threshold value after checking the state of the seat belt. In case of sensor output being higher than the detection threshold value, a warning is triggered by the controller while keeping the stepper motor OFF. If the presence of alcohol is not

detected and the seat belt is strapped, the control unit allows the engine to start. This process ensures that the engine does not run in case either of the two conditions is not fulfilled.

Monitoring of the drowsiness of the driver is carried out with the help of the eye blink sensor while the car is in motion. Prolonged closing of the eyes is taken by the system as a sign of drowsiness. In the prototype that was developed, closing of the eye for more than 4 seconds triggers an automatic alarm to warn the driver.

3.3 Vehicle Condition and Proximity Monitoring

The proposed system will be monitor to sense the operating conditions of the vehicle and the vicinity of other vehicles through the use of the temperature and ultrasonic sensors. The DHT11 temperature sensor is integrated into the system to monitor the vehicle's operating temperature. When the measured temperature exceeds the predefined threshold Temperature > 50°C, the system generates a warning to alert the driver.

Table 1. Sensor conditions and corresponding system responses

Sensor	Monitored Condition	Decision Condition	System Response
Seat-belt sensor	Seat-belt status	Not fastened	Prototype engine remains OFF
MQ3 alcohol sensor	Alcohol condition	Configured threshold exceeded	Warning and prototype engine OFF
Eye-blink sensor	Eye closure	> 4 seconds	Drowsiness warning
DHT11	Temperature	High-temperature condition	Temperature warning
Ultrasonic sensor	Vehicle proximity	Close vehicle condition	Prototype-engine speed reduction
ADXL335	Acceleration	Accident condition detected	GPS acquisition and GSM emergency message

The ultrasonic sensor helps to detect the distance between the proposed vehicle and the car near by vehicle. Once the distance is found to be close enough, the control will execute the vehicle control action accordingly. For the prototype design, the stepper motor serves as the engine of the vehicle. The design is set up in such a way that once there is another vehicle, the speed of the engine will get reduced.

Temperature and distance measurements are functioned by the microcontroller alongside all other sensor inputs. This allows the system to offer proactive solutions while the car is being used even before the accident detection process begins. The sensor conditions and the control response used in the prototype are shown in Table 1.

3.4 Accident Detection and Emergency Geolocation

The proposed system involves using an ADXL335 accelerometer for measuring motion and detecting possible accidents in case of a vehicle in motion. The signals from the accelerometer will be continuously supplied to the ATmega microcontroller, and in case the abnormal impact situation is detected based on the established criterion for accident detection, the signal will be processed by the controller, and the accident response process will be initiated.

The detection of an accident is dependent on the threshold level of the sensor and the logic applied in the controller. For a technically comprehensive definition, it is necessary to define the acceleration threshold, sampling rate, and type of filtering of the signal in accordance with the implementation of the prototype. These parameters determine how accelerometer readings are evaluated to distinguish a potential accident from normal vehicle movement.

Following accident detection, the GPS module detects the geographical position of the vehicle. These latitude and longitude data are processed by the ATmega microcontroller and sent to the GSM module. The GSM module then generate a message with the location details and a link to the Google maps on the specified numbers for the ambulance and police emergency services. This process facilitates the automatic transmission of location details without human involvement.

3.5 Integrated Operating Algorithm

This entire process is managed by ATmega microcontroller. Once the system has been initialized, the seat belt status is checked first. If the seat belt is not in place, the prototype engine

will not start. Once the seat belt status is confirmed, the alcohol status of the driver will be checked using the alcohol sensor.

During the process of driving, the eye-blinking sensor detects the wakefulness of the driver, while the temperature sensor checks the thermal status of the vehicle. There will be an alarm for any detection of drowsiness or high temperature. Meanwhile, the ultrasonic sensor measures the proximity of the other vehicle around the vehicle.

The accelerometer continuously monitors for an accident condition. When an accident is detected, the controller initiates the emergency sequence by acquiring the vehicle location through GPS and transmitting the location information through GSM. The emergency message contains the latitude, longitude, and Google Maps link for communication with the configured ambulance and police contacts. The complete sequence is represented by the proposed operating algorithm.

Algorithm 1. Integrated Vehicle Safety and Accident Detection

Input: Sensor signals from seat-belt, MQ3, eye-blink, DHT11, ultrasonic sensor, and ADXL335

Output: Vehicle control, warning signals, or emergency location message

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1: Begin
2: Initialize ATmega microcontroller and connected modules
3: while system is active do
4:   Check seat-belt status
5:   if seat-belt = NOT FASTENED then
6:     Keep prototype engine OFF
7:     Continue monitoring seat-belt status
8:   else
9:     Check MQ3 alcohol sensor
10:    if alcohol = DETECTED then
11:      Generate alcohol warning
12:      Switch prototype engine OFF
13:    else
14:      Start prototype engine

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15:    while vehicle monitoring is active do
16:        Monitor eye-blink sensor
17:        if eye closure > 4 s then
18:            Activate drowsiness warning
19:        end if
20:        Monitor DHT11 temperature sensor
21:        if temperature = HIGH then
22:            Generate temperature warning
23:        end if
24:        Monitor ultrasonic sensor
25:        if vehicle proximity = CLOSE then
26:            Reduce prototype engine speed
27:        end if
28:        Monitor ADXL335 accelerometer continuously
29:        if accident = DETECTED then
30:            Process accident signal using ATmega
31:            Acquire vehicle location using GPS
32:            Obtain latitude and longitude
33:            Generate emergency message
34:            Send location message through GSM
35:            Exit vehicle monitoring loop
36:        end if
37:    end while
38: end if
39: end if
40: end while
41: return Vehicle control, warning signals, or emergency location message

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3.6 Prototype and Software Implementation

The proposed system is implemented using an ATmega microcontroller together with a seat belt sensor, an MQ3 alcohol sensor, an eye blink sensor, a DHT11 temperature sensor, an

ultrasonic sensor, an ADXL335 accelerometer, a GPS module, a GSM module, and a stepper motor, which acts as a prototype engine. The controller will use the sensor input for the process of verification of the seat belt, detection of alcohol, detection of driver alertness, temperature detection, vehicle proximity detection, and accident detection. Upon the detection of accident, the GPS module will fetch the geographical coordinates while the GSM module will send the emergency message with the location data using Google Maps. The Figure 3 shows the Arduino Serial Monitor display for the prototype system which verifies alcohol status and uses sensor readings for vehicle monitoring.

The embedded software will be designed using the Arduino IDE with Embedded C++ language to program the ATmega based controller. The software environment could include the following libraries to implement a compatible solution: the Adafruit DHT sensor library for DHT11 temperature sensing, TinyGPSPlus for parsing GPS information, SoftwareSerial library for interfacing the GPS and GSM compatible modules, and Stepper library for stepper motor control. The MQ3 alcohol sensor, eye blink sensor, seat belt sensor, and the ADXL335 accelerometer may be interfaced using either digital or analog inputs, based on how they have been connected. The control program manages data acquisition from sensors, condition evaluation, motor control, and emergency communication based on the operation sequence in Algorithm 1.



Figure 3. Hardware implementation of the proposed system

4. Results and Discussion

4.1 System Operation and Serial Monitor Output

The designed prototype was implemented through monitoring the responses produced by the ATmega based control unit within the specified operational settings. The output of the serial monitor illustrated in Figure 4 is indicative of the responses of the controller throughout the operation, including initialization, checking for alcohol condition and then the responses for vehicle status accordingly.

The output display contains the alcohol detection module and shows that there is no abnormality detected in the alcohol level, hence the system continues to the next process which is the driving process. Similarly, the eye blink detection process is shown in the serial output, which is followed by the vehicle status process.

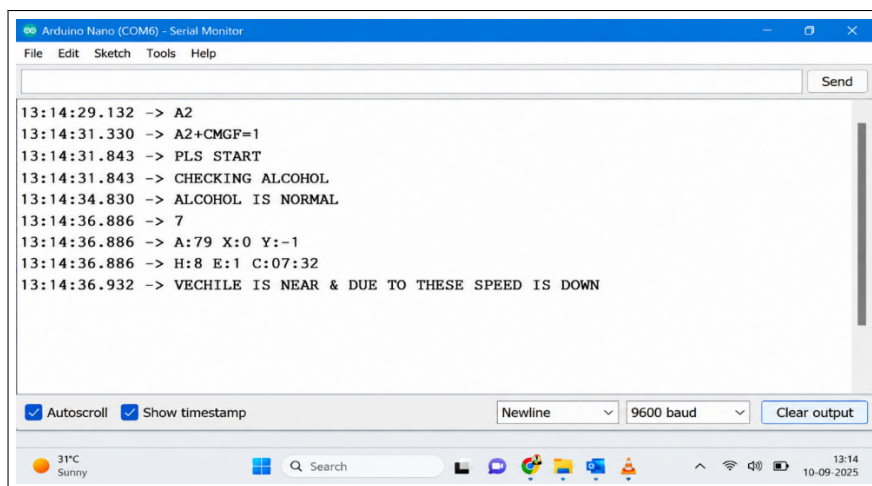


Figure 4. Results recorded in the serial monitor

4.2 Accident Detection and Emergency Notification

Accident detection response was evaluated using the ADXL335 accelerometer and the combination of GPS-GSM communication system. Whenever an accident situation arises, the controller begins the location finding operation using the GPS module to get the geographic location. The GSM module creates an emergency message that contains the accident alert, the geographic coordinates, and the Google Maps address link.

As shown in Figure 5, the emergency message is delivered to the predefined contact with the vehicle accident alert along with the location details. The provided map link shows the

location of the accident incident that helps the concerned person locate the accident site. This is an example of how the accident detection, GPS localization, and GSM emergency messaging can be effectively integrated in the prototype developed.

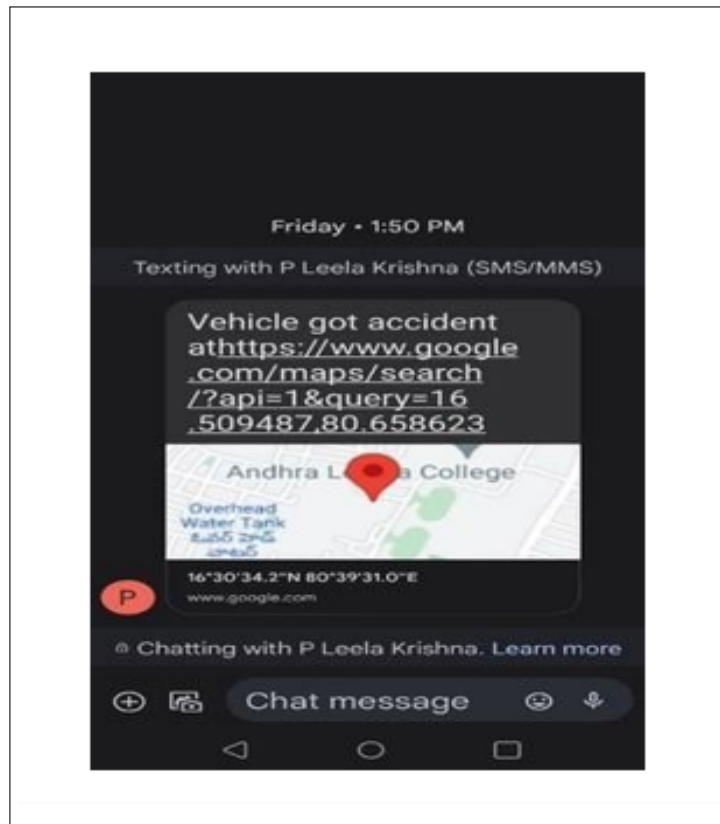


Figure 5. Emergency message generated after accident detection

5. Experimental Analysis

The proposed was tested to analyze the operation of the sensing, control, accident detection, and emergency communication modules under the established operational conditions. The testing was done to analyze the responses of the ATmega microcontroller to the sensor signals and the control actions performed based on them. As can be seen from the serial monitor output shown in Figure 4, the processing is monitor in the order of the sensor signals including alcohol sensing and status of the vehicle.

The accident detection and emergency alert were evaluated through the ADXL335 accelerometer and the GPS-GSM communication system. On detecting an accident situation, the location of the accident was determined through the GPS system controlled by the controller. Figure 5 shows that the GSM module was able to send an emergency message with the accident

alert and location data, as well as the Google Maps URL, to the set-up emergency contact. The test proves that the system is able to function effectively by integrating accident detection, location finding, and emergency message generate.

The overall functional validation covered alcohol condition validation, driver drowsiness validation, temperature validation, proximity of vehicle reaction, accident detection, GPS location detection, and GSM notification. The serial monitors output and the emergency message display provide evidence that the principal hardware and software modules interact according to the intended system workflow.

6. Conclusion and Future Work

The proposed intelligent black-box design combines driver monitoring, vehicle conditions sensing, accident detection, and accident location in the form of a smart embedded system based on ATmega microcontroller. Alcohol sensing, eye blink sensing, seat belt sensing, temperature sensing, ultrasonic sensing, and accelerometer sensing allow for a condition-based reaction, whereas GPS and GSM enable automated accident location reporting. The prototype testing proved the functional operation of sensor monitoring, decision-making through the controller, accident detection, and emergency message transfer. architecture therefore provides a unified approach to preventive for vehicle safety and post-accident emergency communication. Future work will concentrate on testing on actual vehicles under different weather and traffic conditions, setting thresholds for sensors, minimizing the number of accidents detected falsely, and measuring the time taken for communication using GPS or GSM systems. Future research work may include the integration of other vehicle data, monitoring through cloud computing, and intelligent accident classification.

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