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Enhancing Vehicle Safety: Smart Accident Detection Using Vehicle Black Box Technology

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Abstract - This paper introduces a state-of-the-art vehicle black box system aimed at improving vehicle safety through intelligent accident detection and rapid emergency response. The system integrates anarray of sensors and Internet of Things (IoT) technologies to monitor and record critical driving data,enabling real-time accident detection and immediate alert notifications. Key components of the systeminclude accelerometers for impact detection, gyroscopes for assessing vehicle orientation, speed sensors for monitoring velocity, and environmental sensors such as cameras and proximity detectors. Driver condition monitoring tools, like breathalysers for measuring alcohol levels, are also incorporated. Datafrom these sensors is continuously processed in real-time using advanced algorithms designed to identify unusual conditions indicative of accidents. For instance, sudden deceleration combined withabrupt orientation changes can signal a collision. Upon detecting an accident, the system promptly sends alerts to emergency services through a GSM-based communication module. These alerts contain detailed information about the incident, including the vehicle's location, impact severity, and pre- accident sensor data, which is crucial for reducing emergency response times. A significant benefit ofthe vehicle black box system is its ability to provide valuable post-accident data for forensic analysis,helping to determine accident causes and improve future vehicle safety designs. This data aids manufacturers and policymakers in developing better safety regulations and technologies.

Introduction - The continuous evolution of automotive technology has significantly enhanced vehicleperformance, comfort, and safety. Despite these advancements, road accidents remain a major concernworldwide, leading to substantial loss of life, injuries, and economic impact. According to the WorldHealth Organization, approximately 1.3 million people die each year as a result of road traffic crashes,and millions more suffer non-fatal injuries. The need for innovative solutions to reduce the frequencyand severity of these accidents is more pressing than ever. Vehicle black box technology, inspired by the flight data recorders used in aviation, has emerged as a promising tool to address this issue. Thesedevices, also known as event data recorders (EDRs), capture and store critical information about a vehicle's performance and the driver's behaviour in the moments leading up to, during, and immediatelyafter a crash. By providing detailed insights into the factors contributing to accidents, black boxes canplay a crucial role in enhancing road safety and informing future automotive design and policy decisions.

Traditional approaches to accident prevention and analysis have often relied on eyewitness accounts and limited physical evidence, which can be subjective and incomplete. The introduction of vehicle black box technology offers a more objective and comprehensive method of capturing data. These systems provide a continuous stream of information that can be invaluable for accident reconstruction,legal proceedings, and insurance claims. Furthermore, the insights gained from black box data can inform the development of advanced driver assistance systems (ADAS) and autonomous driving technologies, paving the way for safer vehicles and smarter road infrastructure.

This paper presents a comprehensive vehicle black box system designed to improve vehicle safety through smart accident detection and rapid emergency response. The proposed system integrates a wide range of sensors and Internet of Things (IoT) components to continuously monitor and record essential driving data. This real-time data processing capability allows for the immediate detection of accidentsand the prompt transmission of alerts to emergency services. Key features of the system include accelerometers, gyroscopes, speed sensors, and environmental sensors such as cameras and proximitydetectors.

Additionally, the system incorporates tools for monitoring driver conditions, such as eye blink sensors for detecting drowsiness and breathalyzers for measuring alcohol levels. These components work together to provide a holistic view of the vehicle's operation and the driver's state, enabling the detection of potentially hazardous situations before they result in accidents. In the event of a detected accident, the system's communication module swiftly sends detailed alerts to emergency responders, includinginformation about the vehicle's location, the severity of the impact, and relevant pre-accident data. This rapid communication is vital for reducing emergency response times and improving outcomes for those involved in the crash. Furthermore, the system's ability to monitor seat belt usage and issue warnings when belts are unfastened adds an additional layer of safety. Beyond its immediate applications in accident detection and response, the proposed black box system offers significant benefits for post- accident analysis. The comprehensive data captured by the system can be used to conduct forensic analyses, identify accident causes, and inform improvements in vehicle design and safety regulations.By understanding the underlying factors contributing to accidents, manufacturers and policymakers can develop more effective measures to prevent future incidents.

Moreover, the implementation of such systems aligns with broader trends in smart transportation andconnected vehicles. As cities and transportation networks become increasingly integrated with digitaltechnologies, the role of vehicle black boxes in contributing to a safer and more efficient transportationecosystem becomes even more critical. The data collected by these systems can be aggregated and analyzed to identify broader patterns and trends, facilitating the development of smarter traffic management strategies and infrastructure planning.

Literature Survey - Light Detection and Ranging (LiDAR) technology has become a cornerstone inmodern driver assistance systems. A notable study [1] employed a data point clustering algorithm using LiDAR to accurately identify objects around the vehicle. This method enhances the vehicle's perception capabilities, allowing for more precise navigation and obstacle avoidance. Dedicated Short Range Communications (DSRC) technology has been utilized to improve vehicle connectivity and safety. One study [2] demonstrated how DSRC roadside units can detect vehicles that have become disconnectedfrom the network and relay this information to nearby automobiles. This technique ensures that disconnected vehicles are quickly identified and can help prevent accidents. In challenging environments with multiple barriers, accurately determining road borders is critical. Research [3] introduced a combination of technologies that can precisely extract road borders despite obstructions.By integrating high-resolution databases, LiDAR point cloud, and RGB imaging technologies, the study
[4] was able to recognize objects and generate a 3D rectangular representation of the environment. Identifying the driver's facial expression is vital for understanding their state and ensuring safety.

An algorithmic approach was explored [5] for detecting the driver's facial expressions. This method not only identifies the expressions but also assists in locating a safe parking space, allowing autonomousvehicles to navigate there independently. To mitigate accident rates, a multi-sensor approach was proposed [6], combining drowsiness, alcohol, and overload detection sensors. By measuring the eye blinking ratio, the system can determine when to slow down the vehicle. Another study [7] used facial landmark points to track eye flickering rates, further enhancing drowsiness detection. Researchers in [8] suggested a human-computer interaction application that assesses the degree of tiredness by estimating head movements, eye status, and yawning, without requiring any wearable accessories. Alcohol detection within vehicles has been a focus of multiple studies. One research [9] utilized a microcontroller paired with an alcohol sensor to detect the presence of alcohol and included a GSM module to alert the vehicle's owner. Another study [10] described an RFID and alcohol detection sensor system that limits vehicle speed if alcohol levels exceed the limit and automatically collects tolls as thevehicle passes through toll plazas.

Blind spot detection is crucial for both daytime and nighttime driving. Liu et al. [11] suggested usingvarious sensors, radars, and frequencies to detect blind spots. Their method can transmit a warning signal to the driver if unusual movement is detected within the targeted zone. Another technique by Kim et al. [12] involves creating a projection map to alert the driver when motion vectors identify blind spots. RFID technology has also been employed to enhance transportation security. Marigowda et al.
[13] utilized RFID and user architecture to develop a system that allows the host server to instantly evaluate all documentation related to the driver and the vehicle. Li and Zhuang [14] described an RFID- based smart toll collection system that enables toll payment without the driver needing to stop or brake.

Shaik khadar bashal , p.sireesh babu's [15] study focuses on the development of a wireless black box system that incorporates a MEMS (Micro Electro Mechanical Systems) accelerometer and GPS tracking for real-time accident monitoring.

The MEMS accelerometer is a highly sensitive sensor capable of detecting tilts in multiple directions, including forward, reverse, left, and right. The system integratesseveral key components: an accelerometer, a microcontroller unit, a GPS device, and a GSM module.In the event of an accident, this wireless device sends a short message via mobile phone, indicating thevehicle's position by tracing its location through the GPS system. The message is directed to family members, emergency medical services (EMS), and the nearest hospital. A threshold algorithm, combined with the motorcycle's speed data, determines falls or accidents in real-time. The project alsoincludes temperature and CO sensors interfaced with the microcontroller. The temperature sensor measures the amount of heat emitted from the vehicle, while the CO sensor detects the concentration of carbon monoxide gas. If the CO gas level exceeds the threshold limit, the vehicle's motor is automatically stopped. Additionally, an ultrasonic sensor is employed to detect obstacles around the vehicle. If the sensor detects that the distance between the vehicle and an obstacle is too small, the microcontroller calculates the distance and, if necessary, stops the vehicle automatically. The paper byRajashri R. Lokhandel and Sachin P. Gawate [16] presents a system that integrates GPS (Global Positioning System) and GSM (Global System for Mobile Communication) technologies for driver assistance and vehicle surveillance. This system features a wireless black box equipped with a MEMSaccelerometer and GPS tracking to monitor accidents.

The system's key components include a GPS device and a GSM module, working together to provide continuous monitoring. In the event of an accident, the system aims to mitigate the potential loss of lifedue to delayed medical assistance by automatically alerting emergency services. Upon detecting an accident, the wireless device sends a short message via mobile phone, indicating the vehicle's positiondetermined by the GPS system. This message is sent to family members, the nearest police station, andhospitals to ensure prompt medical help. The system employs a threshold algorithm to assess the speedof the vehicle and detect falls or accidents in real-time. This approach ensures that immediate assistance can be provided to the driver and passengers, enhancing overall safety and reducing the risks associated with delayed emergency response. Chetna Bharti and Seema V. Arote's [17] research introduces a real- time, online prototype system designed to monitor driver fatigue. This system utilizes charge-coupled-device (CCD) cameras with active infrared illuminators to capture video images of the driver. Variousvisual cues indicative of a driver's alertness, such as eyelid movement, gaze direction, head movement,and facial expressions, are extracted in real-time and systematically combined to assess fatigue levels.A probabilistic model is developed to interpret these visual cues and predict driver fatigue. The integration of multiple visual cues ensures a more robust and accurate fatigue detection compared to methods relying on a single cue. The system has been validated under real-life conditions with humansubjects of diverse ethnic backgrounds, genders, ages, and with or without glasses, across various lighting conditions. The results indicated that the system is reliable and accurate in characterizing fatigue.

Prototype:-

Vehicle Black Box Prototype is divided into 3 modules:

1. The Control Panel

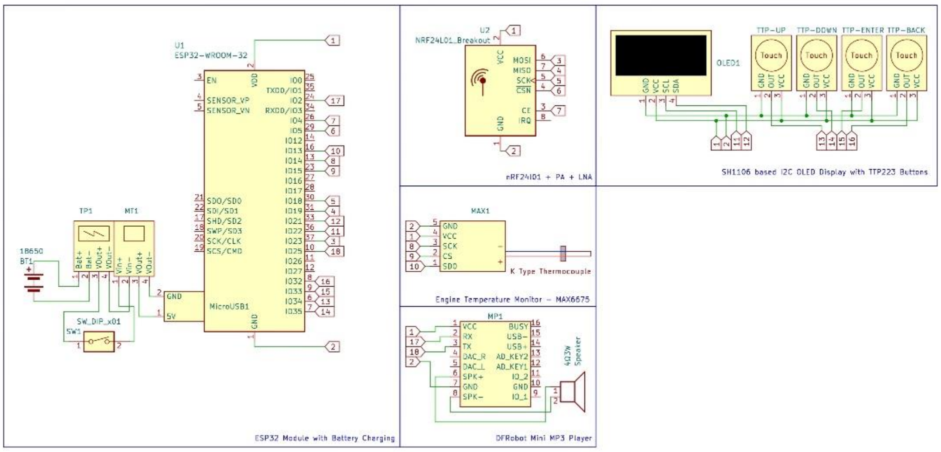

Figure 1: Electronic components of the Control Panel Module

Table of Components and their uses:

Sl.No	Component Name	Use
1.	ESP32	Micro-controller
2.	TP4056	Battery Charging Circuit (NO Load Sharing)
3.	MT3068 DC-DC Step Up Power Module	To provide 5V to the ESP32 mC (from the 3.7V battery)
4.	MAX6675	Cold Junction Compensator
5.	TTP223	Capacitive touch button
6.	1.3” I2C OLED	OLED Display
7.	nRF24L01 + PA + LNA	RF Trans receiver
8.	Nrf24L01 Breakout	Breakout board
9.	MP3-TF-16P	SD Card-based MP3 player board
10.	PAM8403	Class D Amplifier
11.	4Ω 3W Speaker	Speaker
12.	K Type Thermocouple	Temperature measurement
13.	18650 Battery - 2000mAh	To power the circuit

Table 1: Components used in the Control Panel

2. Alcohol, Helmet Detection and Vehicle Speed Simulation Module

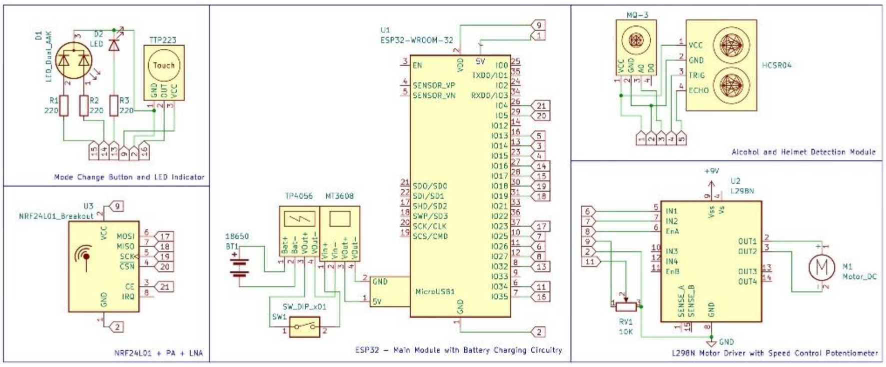

Figure 2: Electronic components of the Alcohol, Helmet Detection and Vehicle Speed Simulation Module

Table of Components and their uses:

Sl. No.	Component Name	Use
1.	ESP32	Micro-controller
2.	TP4056	Battery Charging Circuit (NO Load Sharing)
3.	MT3608 DC-DC Step Up Power Module	To provide 5V to the ESP32 mC (from the 3.7V battery)
4.	18650 Battery - 2000mAh	To power the circuit
5.	NRF24l01 + PA + LNA	RF Trans receiver

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6.	NRF24l01 Breakout	Breakout board
7.	MQ-3 Alcohol Sensor	Alcohol Detection
8.	HC-SR04	Ultrasonic sensor - Helmet detection
9.	L298N	Motor Driver
10.	10K POT	Speed Control - Simulation
11.	300 RPM BO Motor	Simulation Purposes
12.	3mm Dual Colour LED	Status Indicator
13.	TTP223	Capacitive touch button

Table 2: Components used in the Alcohol, Helmet Detection and Vehicle Speed Simulation Module

3. Accident Detection Module

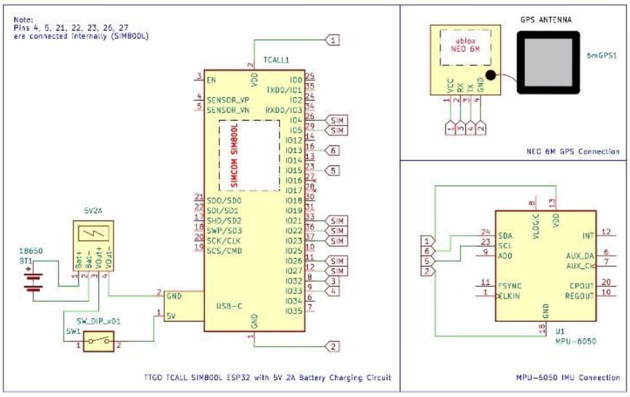

Figure 3: Electronic components of the Accident Detection Module

Table of Components and their uses:

Sl. No	Component Name	Use
1.	MPU-6050 IMU	Accelerometer + Gyroscope Readings.
2.	NEO-6M GPS	Location Coordinates, Speed
3.	TTGO TCALL ESP32 SIM800L	Micro-controller + GSM Module
4.	5V 2A Charge & Discharge Module	Charging battery and discharging to power up the circuit
5.	18650 Battery - 2600 mAh	To power up the circuit

Table 3: Components used in the Accident Detection Module

Working:- The planned modules are first installed into the vehicle. The modules are set to run automatically when the driver starts the vehicle.

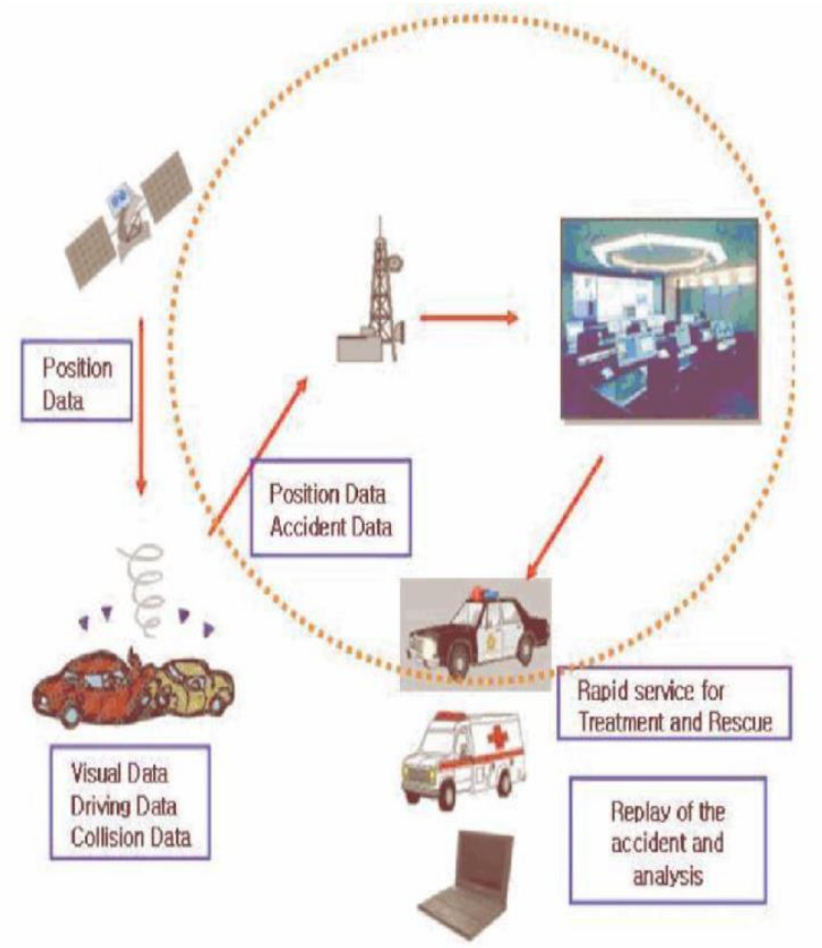

Figure 4: Concept of Vehicle Black-Box with collision avoidance system

Vehicle black box records three different things i.e. information about the driving data and the position data. Driving data includes speed of the vehicle, engine temperature, state of the driver (intoxicated or not) and whether the driver has worn a helmet or not (in 2-Wheeler mode) while driving by various sensors and stores in its memory. Position data includes the exact location in terms of latitude and longitude values where the vehicle met with accident with the help of GPS module, The driving data and position data is sent wirelessly to the nearest emergency medical service/ relatives through GSM module.

Vehicle Black Box Prototype is divided into 3 modules:

1. Module 1: The Control Panel

Engine temperature is measured with K type thermocouple placed near the engine area. An audio feedback is provided via a 4 ohm, 3W speaker and DFRobot MP3 MINI in case of any anomaly such as over-speeding, influence of alcohol, high engine temperature, collision etc.

For interacting with the user interface of the control panel, the prototype includes an I2C 1.3" OLED display and four TTP223 touch sensors for the purpose of navigation between 3 different modes namely, 1. Four-wheeler mode, 2. Two-wheeler mode, 3. Simulation mode.

There is button present which can used to toggle between the normal mode and simulation mode.

There are two LED indicators present on the control panel. One bi-colour LED shows blue light if no violation are present and red light in-case of any violation. The other LED glows if the simulation mode is enabled.

The control panel module consists of a nRF24L01, which is a wireless transceiver module that operates in the worldwide ISM frequency band, used for RF communication with the other remote modules.

This module is powered by two 3.7v 2600mAh 18650 Li-ion rechargeable cell, connected to the TP4056 chip, which is a complete constant-current/constant-voltage linear charger for cell Li-ion batteries.

The Control panel communicates with the Accident module via ESP-NOW communication protocol. Any warning that is generated by the user interface will be wirelessly transmitted and the according error message will be shown on the display and according audio will be played through speaker. The control panel only receives information from the remote module and further transmits this data to the accident module.

The ESP32 microcontroller is used to program the user interface and control various components. This microcontroller requires a 5V power supply to operate. Since the Li-ion batteries supply only 3.7V, a boost convertor is equipped in this module.

2. Module 2: Alcohol, Helmet Detection and Vehicle speed Simulation Module

This module consists of a HCSR04 Ultrasonic sensor for helmet detection, a MQ-3 Alcohol sensor for detection of intoxicated driving and a L298N motor driver along with a motor attached to a wheel to simulate the speed of a vehicle. The data generated by all these components are sent to the control panel module for alert generation.

The ultrasonic sensor measures the distance between the face and the mouth piece region of the helmet to determine if the person is wearing a helmet. This data is not considered if the user has chosen either Four-wheeler mode or Simulation mode.

The MQ-3 sensor measures the alcohol in mg/dL. The legal limit is below 30mg/dL. Any violation detected is sent to control panel via the nRF24L01.

The L298N is a dual H-bridge motor driver which can control the of up to two motors via PWM signals. A 10K ohm potentiometer is used to control the speed of the motor. The potentiometer gives an analog input which is corresponded to a suitable PWM value to drive the motor. If the PWM value exceeds 80, the motor is said to operate in over-speeding condition.

3. Module 3: Accident Detection Module

This module consists of a MPU-6050 device which combines a 3-axis gyroscope and a 3-axis accelerometer on the same silicon die, together with an onboard Digital Motion Processor™ (DMP™), which processes complex 6-axis MotionFusion algorithms. This Inertial Measurement Unit (IMU) device detects G-forces higher than 4G's to detect accidents.

This module also consists of Neo-6M GPS module used to determine location in case of an accident, speed of the vehicle, time etc.

Lastly, the module consists a TTGO-TCall ESP32 SIM800L which works on 2G networks to publish data to the cloud and to send messages to the concerned people and authorities.

All the three modules mentioned above communicate to facilitate accurate alert generation and collision avoidance.

Results and Discussion:

The designed module consists of various sensors which are capable of measuring different parameters like over-speeding, alcohol detection, engine overheating, and accident detection. The recorded sensor values are sent to the cloud which are very useful in post-accident investigations. The message is displayed in the phones of concerned people and authorities after the accident is occurred to the vehicle. This is sent to the emergency numbers by the SIM800L module which is fixed in the vehicle. It even shows the location, date and time of the accident. The information is displayed on the phone once after the collision has occurred. The driver is intimated through buzzer when the engine temperature goes high. The GPS detects the latitude and longitudinal position of a vehicle where exactly the accident occurred and this information is sent through SIM module to the pre-saved numbers so that they can take an immediate action to provide rapid service for treatment and rescue. Later the stored information from black box can be used for replay of the accident and analysis.

The three modules were able to successfully communicate with each other in appropriate order. Several disturbances were provided to the accident module to detect for accidents and messages were generated accordingly. Also, violations by the driver like alcohol and helmet were also detected. Speed simulation was also tested successfully and gave satisfactory results.

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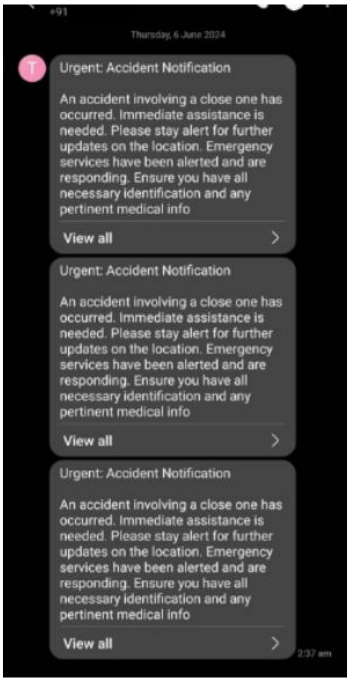

Figure 5: Snapshot of the alert messages received through SMS in-case of any violation

Applications:

For Personal Vehicle

If the vehicle is fitted with black box, and if suppose accident occurs immediate action for treatment can be

provided on receiving the message.

B. Insurance Companies

Many times, the accident is not true. So, insurance companies can implement this designed module in the insured vehicle, so with the help of recorded data they can easily analyse the accident detail. So, they can predict whether the accident happened due to the driver's fault or occurred.

C. Research and Development of Vehicle

Here the engineers require various recorded parameters like speed of vehicle, temperature etc. So, they use recorded information from this black box for the development purpose.

D. Military Applications

If military vehicles is fitted with black box, then if at sudden any militants had attacked or vehicle damage occurs, immediately SMS can be sent to authorized organization.

Conclusion:

The black box with collision avoidance can be fitted in any vehicles. Once immediately the driver starts the vehicle, the developed module with various sensors measures the different parameters in real time once in every 5 seconds and the information will be stored in the memory. As soon as the accident occurs the SMS will be sent to the pre-saved numbers so immediate action can be taken to provide treatments. If any of the sensor values varies the desired threshold levels, driver can be intimated through buzzer and even by displaying information on display. The information stored in black box can be used later for analysing the accident detail, and to solve disputes in insurance companies and this information can be even helpful in improvement of roadway design, vehicle designs.

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