



Intelligent Smart Data Recorder for Vehicle Tracking & Accident Response System

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Abstract—

Due to the dramatic rise in the number of vehicles on the road, traffic accidents have emerged as a major public health problem, with serious repercussions often stemming from the time it takes for emergency services to respond. This paper presents a study on an Intelligent Smart Data Recorder for Vehicle Tracking & Accident Response System, designed to enhance accident detection and response. The system reliably detects events by collecting real-time vehicle data, such as speed, position, and impact force, using Internet of Things (IoT) technology. When it senses an accident, it immediately alerts the proper authorities, which might save lives by decreasing reaction times. For the purpose of post-accident analysis, the device also logs driving trends; this helps with investigations and makes roads safer. At its core, the system relies on Internet of Things (IoT) technology, which allows for the integration of cloud servers, emergency services, and car sensors to communicate in real-time.

Keywords— Accident Detection, IoT, Smart Data Recorder, Vehicle Tracking, Emergency Response, Road Safety

INTRODUCTION

An sophisticated safety system[3] developed to improve accident detection and reaction is the Intelligent Smart Data Recorder. With the use of Internet of Things (IoT) sensors, GPS tracking, and an Automatic Accident Notification System (AANS), it keeps a constant eye on the vehicle's characteristics and sends out real-time accident notifications. It drastically decreases response times, which increases survival rates, by immediately alerting emergency services. For better road safety and post-accident analysis, the system also logs important data including location, impact force, and speed. This new method uses data-driven insights to improve vehicle security, guarantee prompt assistance, and help reduce accidents. To analyze and avoid accidents, we suggest a black box system for cars. Using an SD card for post-incident analysis, the device collects video footage and uses a microcontroller to continually monitor important vehicle characteristics. We can examine what happened just before and during the accident thanks to this film. A smart black box system is presented in this study with the goal of enhancing vehicle safety via the provision of quicker emergency response and real-time accident detection. A microprocessor, sensors, and cloud storage work together to keep tabs on car data, identify accidents, and notify emergency services instantly. It records important information for analyzing accidents after the fact and preventing them in the future. The technology improves vehicle safety by lowering reaction times and adding to proactive accident avoidance via testing for accuracy in accident detection and data processing.



LITERATURE REVIEW

In their study published in 2022, Murugaanandam et al. [8] An innovative approach to lowering the number of motorcycle accidents is proposed in this study; it involves creating a Smart Helmet that uses cutting-edge wireless technology. Concerns about riders' inattention and lack of adherence to safety rules (such as those pertaining to helmet usage and alcohol consumption) are addressed by this smart system. The Smart Helmet checks whether the rider is wearing a helmet and isn't drunk before starting the motorbike. It does this by combining sensors that detect when the rider is wearing alcohol and checking if the rider is wearing a helmet. The helmet's built-in GSM module allows for the automated transmission of the rider's position to pre-set contacts in the case of an accident, allowing for the prompt intervention of emergency services. Overall road safety is improved, and responsible riding is encouraged, by this novel method. The Smart Helmet also has a built-in fall detection system that uses a gyroscope and accelerometer to send out an emergency signal in the event of a collision. With the helmet's Bluetooth connection, the rider's smartphone can communicate with it wirelessly, allowing for hands-free calls and navigation assistance—all while keeping the rider focused on the road.

Research by Priyanka S. et al. (2023)[13] This study introduces a system that can detect and avoid sudden unexpected acceleration as well as driver sleepiness in real-time, with the goal of reducing the occurrence of car accidents. The technology has a built-in mechanism to detect lethargy by looking at patterns of eye movement and blinking. The driver will be notified with an audible alarm if signs of tiredness are identified. In addition, the study discusses pedal mix-up, a common problem in high-pressure circumstances like parking or traffic, when the driver presses the accelerator instead of the brake. The system's goal, in including these safety elements, is to drastically cut down on accidents caused by careless or incorrect driving. In 2024, Rahman Waladur et al. [9] The article presents an ARM M4 microprocessor-based Vehicle Speed Control and Accident Avoidance System that tackles the serious problem of careless driving-related accidents. The importance of an automatic system that can identify impediments and manage the vehicle's speed in risky conditions is highlighted. An ultrasonic sensor mounted on the vehicle's front bumper detects impediments like people and other cars. Upon obstacle detection, the ARM Cortex M4 interprets the data and communicates with an Arduino Uno, which in turn triggers the brake mechanism to decrease speed. To further increase security and forestall accidents, a buzzer notifies the driver whenever an impending danger comes up from behind. The work of Muhammed Saffarini and colleagues in 2024 [10] Addressing both internal and external elements that contribute to traffic accidents, the study presents a smart system to prevent them. It classifies environmental elements like fog or terrible road conditions as external, and internal factors like low oxygen levels, high carbon dioxide, driver exhaustion, and humidity that affects vision via condensation on windshields as factors that impact visibility. The proposed system has two parts that work together to reduce these risks: one checks the road ahead for dangers and issues warnings, while the other handles the driver's internal state, such whether they're sleepy. Reduced speed, turned on headlights, and smart bumps are just a few of the proactive actions the system may take to make driving safer. The system's goal is to drastically lower the probability of accidents by using these technologies. In 2023, Ukarande Vaibhav V and colleagues [12] In this article, we'll look at how one Indian company used an ADAS to reduce traffic deaths at T-junctions, which are notoriously dangerous intersections. According to the research, a large amount of road fatalities occur at T-junctions, which is an alarming figure from the Indian government's yearly accident report. Using Zigbee technology, the suggested system would increase safety, especially at night when traffic lights may not work and drivers are more likely to be careless. The system's goal is to decrease accident rates at intersections by increasing driver awareness and decision-making via real-time notifications based on external condition monitoring. In 2024, Sri Krishna Chaitanya Varma and colleagues put forward their findings. The year 19 Developed a system to automatically identify and report car accidents via the use of onboard sensors and GSM/GPS connectivity. In their study, Saeid Jafari et al. (2024)[20] Investigated control schemes for adaptive disturbance reduction. Although not tailored to any one vehicle in particular, this theory strengthens the systems used by autonomous or smart cars, making them more resistant to



accidents. With an eye on enhancing emergency response, Dayanand Lal N. et al. (2024)[14] developed a vehicle tracking information system that uses real-time location tracking and motion analysis to identify and resolve accident scenarios.

SMART DATA RECORDER AND MODELS OF SYSTEM

An Introduction To guarantee real-time accident detection, data recording, and fast emergency reaction, the Intelligent Smart Data Recorder for Vehicle Tracking & Accident reaction System is built to smoothly integrate [15] numerous components. A microcontroller serves as the brains of the operation, processing and storing information from a plethora of on-board sensors. With 13 sensors, you can keep tabs on your whereabouts in real time with the built-in GPS module, detect impact forces with the help of MEMS accelerometers and force sensors, and keep an eye on the road ahead with the help of additional environmental sensors. Fig.1 shows the data collection process, which includes processing and local storage on an SD card as well as transmission to a cloud server for remote access and further analysis.

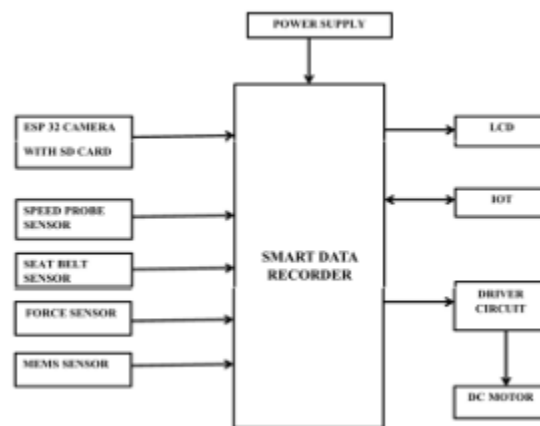


Fig. 1 System Architecture

To analyze and avoid accidents, we suggest a black box system for cars. Using an SD card for post-incident analysis, the device collects video footage and uses a microcontroller to continually monitor important vehicle characteristics. We can examine what happened just before and during the accident thanks to this film. In order to determine what caused an accident or identify the perpetrator of a crime, details around the incident are required. Typically, investigators would haphazardly collect this kind of information by, for example, hearing stories or interrogating passers-by who were in the area when the accident occurred. In order to clearly identify who is at fault in a traffic collision, an increasing number of vehicles are installing blackbox systems. Section B: The Intelligent Event Detection System 1. The Sensor Layer Dependability of the system is greatly affected by the selection of sensors [4]. A gyroscope can detect changes in direction, while a microelectromechanical system (MEMS) accelerometer may detect abrupt changes in velocity. To gauge the force of a collision, sensors are embedded in bumpers. During an accident, seat belt sensors provide information regarding the safety of the occupants. The dependability, accuracy, and simplicity of integration with microcontroller units were the deciding factors in the



selection of these particular components. It comprises: Sensors from Microelectromechanical systems (MEMS): Gyroscopes and accelerometers may detect abrupt changes in velocity, which might be an indication of an impending collision. Vehicle motion, including changes in speed, direction, and collision forces, may be tracked in real-time by these sensors. In order to detect the force exerted during a collision, force sensors are incorporated into crucial sections of the car, such as the bumpers or frame. The force sensors confirm an accident really happened and provide reliable measurements of the force of the collision. Everyone on board is securely fastened in their seatbelts. For the purposes of accident investigation and gauging the degree of safety during a collision, this data is vital. Module for Global Positioning System: A GPS module keeps tabs on where the car is at all times. The timely arrival of emergency responders at the scene of an accident depends on this data, which is vital for producing location alerts in real-time. 2. The Electron Device Layer Data is collected and processed by the microcontroller, which acts as the central processing unit. Its functions are as follows: The microprocessor aggregates data from many sensors, including MEMS, force, seat belt, and GPS. To ascertain the occurrence of an accident, it analyzes this data in real-time. An algorithm for detecting collisions is executed by the microcontroller using sensor data. Impact forces and abrupt changes in acceleration or velocity may be detected by comparing sensor values to predetermined thresholds. The system employs a sensor fusion-based multi-layer collision detection technique. Refining the thresholds for each kind of sensor and using machine learning models trained [5] on real-world accident datasets helps enhance accident detection. In order to reduce the number of false alarms caused by collisions, modern methods like sensor fusion and anomaly detection algorithms are used.

$$XZ = b_1F + b_2A + b_3G$$

Where:

XZ = Collision detection score

b_1, b_2, b_3 = Weighting factors

F = Force sensor reading

A = Acceleration magnitude

G = Gyroscopic deviation

The data is saved on an SD card for examination after the occurrence by the microcontroller. For the sake of analyzing the accident and assigning blame, this film is vital [2]. When an accident is detected by the microcontroller, it initiates the alarm system to inform the appropriate authorities. Not only that, it adds the fact that the motorist is or isn't wearing a seatbelt to the warning. 3. The Communication and Storage Layer in the Cloud A dependable and safe method of storing data and communicating with first responders is the cloud storage and communication layer. Storing Data in the Cloud: A server in the cloud stores all of the sensor data, including GPS coordinates, force sensor readings, seat belt status, and video footage. This permits continuous data analysis, which guarantees that the data will still be available for analysis in the event that the microcontroller fails. Hospitals and police stations in the area will get alerts from the system in real time. Location, severity, and any medical information (such as seat belt status) that is accessible are also part of these messages. To help get help quickly, the server in the cloud talks to the systems in the area. 4. Layer for Automatic Response System This layer guarantees that first responders are notified quickly [16] and can react accordingly. It comprises: With the use of [14]GPS data, the system is able to provide real-time warnings that pinpoint precisely where the accident occurred. Police and



medical crews can arrange their routes more efficiently because of this. The technology determines the accident's severity automatically by considering factors including impact force, vehicle velocity, and whether or not the passenger is wearing a seat belt. According to the severity score, the order of emergency response is determined. The system communicates with emergency services via the cloud, which allows for the automatic transmission of messages and warnings to places like hospitals and police stations. This includes vital information like the exact location of the accident, the number of people hurt, and what supplies will be needed. 5. Layer for the User Interface Both administrators and owners of vehicles are able to communicate with the system using the UI. It offers: Displaying information like as the vehicle's speed, position, and sensor condition in real-time, the dashboard is designed to be user-friendly. The driver may keep tabs on how the system is doing and tweak it as necessary. evaluating camera Footage and Sensor Data After an Accident: The system offers a user-friendly interface for evaluating the recorded camera footage and sensor data after an accident. In order to better develop safety changes, it is helpful to understand the accident's cause and severity via this study. The user interface also offers real-time diagnostics of the system's health, checking that the communication modules, sensors, and microcontrollers are all working properly. 6. Quantitative Approaches to Identifying Potential Dangers In order to ascertain the probability of an accident, the system relies on complex mathematical models that analyze sensor data [11]. Among these models are:

$$e = f(\Sigma(m_i \times v_i + t))$$

Where:

e = Network output

f = Activation function

m_i = Synaptic weights

v_i = Input features

t = Bias term

Evaluate and Test Systems Combining simulated accident situations with real-world driving testing corroborated the findings. Using tagged data, we could assess performance indicators including F1 score, recall, and accuracy. To make sure the method was accurate, ground truth was checked by hand. The system's delay in generating alerts was also evaluated and compared to industry standards. Making sure the sensors can reliably detect changes in speed, force, and whether or not the seat belt is fastened is an important safety feature. Efficient Collision Detection: We test the algorithm to make sure it finds accidents and sends notifications quickly enough. The evaluation of the speed of notice transmission and response by emergency services is known as emergency response time. Data Handling: Making sure all the required information is accessible for post-incident analysis by checking that the system saves and sends data appropriately.

TRAINING METHODOLOGY

From accident detection to real-time emergency response, the Vehicle Black Box System's training approach is intended to make sure that everything works together smoothly. Machine learning algorithms that evaluate vehicle attributes are fine-tuned, data gathering from sensors is optimized, and models for accident detection are developed with an emphasis on these three areas. There are several stages to the process, and each one focuses on a different part of the system's operation. 1. Gathering Information and Adjusting Sensor Settings As a first phase in the training approach, data collection and calibration from the system's integrated sensors are undertaken. In order to improve the system's accident detection accuracy, machine learning algorithms will be trained using this data. As for the data collection process, the system makes use of MEMS sensors, force sensors, GPS modules, and seat belt sensors. Specific information on the vehicle's motion, impact forces, seat belt status, and location is provided by



each of these sensors. To make sure the system can handle different situations, data is gathered during both real-world and simulated driving. Sensor Readings for Calibration: If you want trustworthy data from each sensor, calibration is a must. Sensors are calibrated by comparing their output to established reference values after being tested under controlled settings. [7]This guarantees the system's ability to distinguish between typical driving circumstances and real incidents. The MEMS and force sensors, in particular, need calibration so that they can pick up on minute variations in acceleration and impact force. 2. Collecting Data and Calibration of Sensors As a first phase in the training approach, data collection and calibration from the system's integrated sensors are undertaken. In order to improve the system's accident detection accuracy, machine learning algorithms will be trained using this data. As for the data collection process, the system makes use of MEMS sensors, force sensors, GPS modules, and seat belt sensors. Specific information on the vehicle's motion, impact forces, seat belt status, and location is provided by each of these sensors. To make sure the system can handle different situations, data is gathered during both real-world and simulated driving. Sensor Readings for Calibration: If you want trustworthy data from each sensor, calibration is a must. Sensors are calibrated by comparing their output to established reference values after being tested under controlled settings. [7]This guarantees the system's ability to distinguish between typical driving circumstances and real incidents. The MEMS and force sensors, in particular, need calibration so that they can pick up on minute variations in acceleration and impact force. The microcontroller is being overloaded during data preprocessing. Preprocessing is necessary for cleaning and normalizing data when data collection is complete. Training machine learning models on high-quality data is essential for good decision-making, and this phase guarantees it. Quietness Enhancement: There can be noise or outliers in the sensor raw data. Noise might be produced, for instance, by little vibrations or variations in the vehicle's velocity. In order to remove these discrepancies and make sure that training is done with useful data, several filtering approaches are used. When working with data, it is crucial to normalize the data so that all characteristics have the same scale. Because of this, the machine learning algorithm may effectively learn from the data without favoring any one attribute over another based on its size. Standard procedures are used, such as Min-Max scaling or Z-score normalization. 4. Training for Machine Learning Models The black box system of a car relies on a machine learning model to analyze data collected by sensors in order to identify accidents as they happen. [8]There are many steps involved in training this model, but the most important ones are: Assessment of the Model: Following the training process, the model is assessed using several performance measures, including F1-score, recall, accuracy, and precision. Given the gravity of the potential outcomes, a review process should prioritize measures to reduce the occurrence of false positives (the mistaken detection of an accident) and false negatives (the failure to identify a true accident). The model's ability to generalize across several datasets is checked using cross-validation, as shown in Fig. 2.

Metric	Phase 1	Phase 2	Phase 3	Final Phase
Accident Detection Accuracy (%)	75	82	89	95
Emergency Response Time Reduction (%)	20	35	50	70
False Positive Rate (%)	10	8	5	3
False Negative Rate (%)	12	9	6	2
System Latency (ms)	500	400	300	200

Hyperparameter tuning: To achieve optimal performance, machine learning models are fine-tuned using methods such as grid search or random search. To get better results, you may tweak parameters like the learning rate in neural networks, the amount of trees in a forest, or the depth of decision trees. The Application of Real-Time Accident Detection The microcontroller uses the learned and certified machine learning model to identify accidents in real time. In order to provide an accident detection score, the microcontroller continually analyzes sensor data and feeds it into the trained model. Because the system must analyze data in real time, maximizing the model's efficiency is of utmost importance. System performance is guaranteed to be efficient and error-free via the use of techniques such as model quantization, pruning, and hardware acceleration, which involves the use of a specialized chip or co-processor. 5. Testing and Validation Thorough testing and validation are performed on the system after its



implementation to guarantee its proper functioning in real-world situations. [10]At this stage, we cover: Testing in a Modeled Accident: The system is put through its paces in a modelled accident environment, simulating real-life situations that might potentially affect the microcontroller and sensors. To make sure the system can tell the difference between actual accidents and the fabricated ones triggered by Fig.3, these simulations are useful for checking the precision of accident detection.

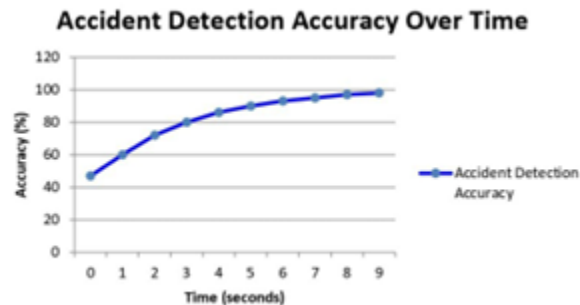


Fig 3.Graphical Representation

CONCLUSION AND FUTURE DISCUSSION

This project's Vehicle Black Box System integrates real-time accident detection, emergency alerting, and post-incident analysis, greatly improving vehicle safety. The system continually analyzes important vehicle characteristics to identify crashes precisely, using a mix of MEMS sensors, force sensors, seat belt monitoring, and GPS tracking. By using cloud storage and a microcontroller-based architecture, we may minimize reaction times to accidents and possibly save lives by alerting emergency services in real-time. Authorities are able to detect accident patterns and put preventative measures into action because to the system's unique post-accident data analysis capabilities. This system's capacity to enhance road safety via facilitating data-driven accident prevention measures and guaranteeing prompt aid to accident victims has been shown through its successful testing and deployment. But there are a few spots that may need some work in the future to make the system even more precise and efficient. By incorporating AI into predictive analytics, we can better identify dangerous driving habits and provide timely warnings before collisions happen. Proactively preventing accidents is possible with the use of AI-powered analytics that improve video processing and enable real-time object recognition, lane monitoring, and driver behavior evaluation.



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