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Smart Automotive Black Box System with Emergency Alert

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ABSTRACT: This paper describes a smart automotive black box system that can monitor in real time, find accidents, and analyze what happened after they happen. The suggested system uses a number of sensors, such as a temperature sensor, an accelerometer, a speed sensor, a camera module, an alcohol sensor, and an OBD-II interface, to gather a lot of information about the vehicle and the driver.An SD card module stores all the data collected on the device itself, and at the same time, the data is sent to the ThingSpeak cloud platform for real-time monitoring and analysis. If there is an accident, the system automatically detects the impact and sends an alert message to pre-set emergency contact numbers along with the live location using GPS and GSM modules.

KEYWORDS: Black Box System, thing speak, Cloud Monitoring, accelerometer, OBD Interface.

I. INTRODUCTION

Road accidents have become a big problem around the world in the last few years, killing and damaging a lot of property. One of the biggest problems with managing accidents is that there isn't always quick access to information about the event, which slows down emergency response. To fix this problem, modern transportation has made advanced vehicle monitoring and data recording systems more important.[1.A smart automotive black box system is made to keep an eye on and record important information about the car and the driver's behavior all the time. This system is like the black box used in planes; it helps figure out what caused accidents and gives investigators useful information. Real-time data monitoring and remote access are now more reliable and efficient thanks to the addition of Internet of Things (IoT) technology.If there is an accident, the system will find out what happened and send alert messages to a list of emergency contacts along with the person's current location using GPS and GSM modules. Also, only authorized users can access the stored data to protect its security and privacy.This system's goal is to make roads safer, speed up emergency response, and give reliable data for analyzing accidents after they happen. This makes it a useful solution for smart transportation systems.The system uses a combined hardware setup that includes a high-precision accelerometer and gyroscope sensor to detect sudden impacts or unusual tilting of the vehicle.When a potential accident is recognized, the GPS module (Neo-6M) quickly captures the exact latitude and longitude coordinates. The microcontroller processes this data and sends it through the GSM module as an automatic SOS alert to a pre-defined list of emergency contacts and medical services. This way, help can get to the victim during the 'Golden Hour,' greatly improving the chances of survival. [1].

This project addresses a critical gap in modern road safety by integrating real-time tracking with automated emergency signaling. By eliminating the dependency on manual reporting during life-threatening situations, the system ensures that medical aid is dispatched without delay. Furthermore, the inclusion of a secured data logging feature transforms the vehicle into an intelligent entity capable of providing objective evidence for legal and diagnostic purposes. Ultimately, this innovation not only aims to reduce fatality rates on highways but also serves as a foundational step toward building a more resilient and responsive smart transportation ecosystem."

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II. BACKGROUNDANDMOTIVATON

A. Rising Incidence of Road Accidents and Global Safety Concerns

Currently, The world is currently witnessing a silent epidemic in the world of automobiles and road transportation, as evidenced by the exponential rise in road traffic accidents and fatalities. As per recent World Health Organization (WHO) reports and world-wide transport statistics, road traffic injuries have become the largest cause of mortality for children and young adults in the age group of 5-29 years, causing almost 1.3 million fatalities each year [1, 4]. In a large number of cases, especially on high-speed motorways and deserted road stretches, accidents often remain undiscovered for hours as the victims remain in an unconscious state, making it impossible for them to send a manual distress signal [2, 10]. This lack of human intervention in reporting becomes a dire necessity for an autonomous intervention system that does not require the physical state of the victims.

Furthermore, the rising density of vehicles within the "Smart City" environment has resulted in an increase of complex types and 'blind spot' accidents that are beyond the monitoring capacity of conventional surveillance systems. Public safety infrastructures within developing nations face the challenge of inconsistent response time due to the inaccurate location reporting of witnesses under emergency conditions or the lack of witnesses altogether [5, 8].

The rationale behind the research is the socio-technical imperative to move from 'Passive' safety measures like seatbelts to 'Active' digital monitoring of every vehicle to ensure it becomes an intelligent sensor that reports its status.

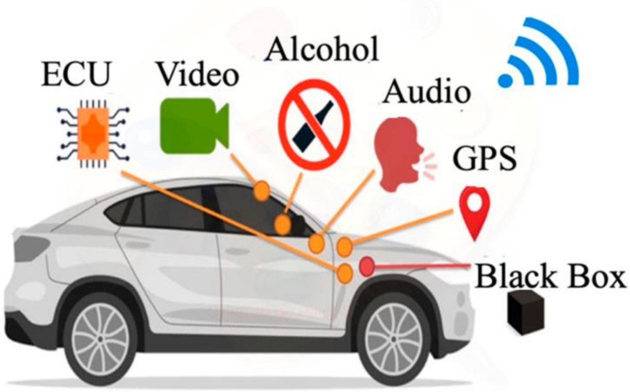

Fig1: Design of a car Black Box System

B. Need for Continuous and Real-time Vehicle Monitoring Systems

However, modern vehicle safety cannot be achieved merely through reactive methods. A proactive and continuous monitoring approach is essential for monitoring the dynamics of a vehicle in real-time. The technical reason for this is to develop a high-fidelity sensing layer using Micro-Electro-Mechanical Systems (MEMS) devices. By employing the MPU6050 device, which is a 3-axis accelerometer and 3-axis gyroscope sensor that includes a Digital Motion Processor, it is possible to read the vehicle orientation and acceleration at high rates [11, 20]. This continuous monitoring is crucial in distinguishing between "environmental noise," such as "potholes and sudden braking," and "collision signatures," which are indicative of a real "collision." Without such monitoring, it is virtually impossible to detect low-impact rollover and side impact collisions, resulting in a loss of lives.

The need for such a system is also underscored by its capacity to deliver a "real-time health status" of the vehicle's motion, thereby ensuring that the embedded controller is always "ready to go" for emergency execution. The constant flow of data ensures that even the slightest deviation from normal and safe driving parameters, such as extreme tilt and high-G impacts, is immediately recorded and processed [15].

This is a form of preventative measure, where the system is not merely waiting for accidents to happen but is, in a manner of speaking, "aware" of what is going on. This is a basic requirement for ensuring that trust is built into technical solutions for autonomous safety, where there is a seamless transition from human to machine assistance [17, 23].

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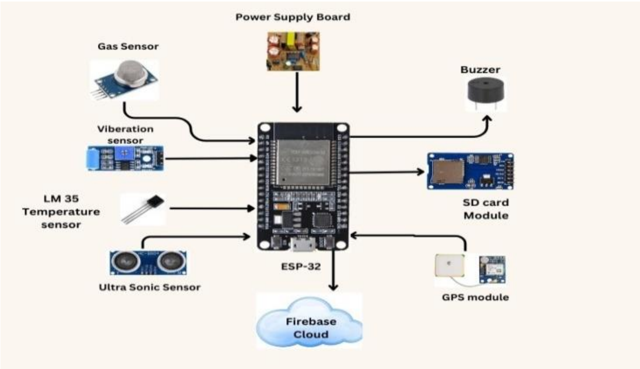

Fig2: Basic block diagram

C. Importance of Rapid Accident Detection and Emergency Response

In the domain of emergency medicine, the "Golden Hour" is considered to be the most critical time for interventions for a patient with a trauma injury [5]. Research shows that if a patient is taken to a tertiary care facility within 60 minutes of injury, there is a significant reduction in mortality rates.

The most significant time delay in the current chain of emergency response is the "Detection-to-Notification" time, which is reported to take more time than the actual time taken to transport the patient to the hospital [3], [5]. This project is motivated by the idea of minimizing this time delay to almost zero by using high-precision embedded technology for the entire dispatch process [2], [3].

The inclusion of GPS modules such as NEO-6M will help avoid confusion regarding location reporting, which is reported to be the most difficult part of the journey for ambulances, especially in unfamiliar terrain [9], [22].

Fig3: Transfer of Information

At present, emergency services rely on information provided by eyewitnesses who might be in a state of shock and hence give vague and incorrect information about the exact location of the accident site. With an automated system, NMEA sentences from satellites are directly obtained and give precise coordinates in terms of latitude and longitude [14], [22].

Thus, the emergency team knows exactly where to go and does not waste time on incorrect information provided by human observers [16]. With the help of GSM communication protocols through sim cards like SIM800L, it is ensured that emergency contacts and medical services are informed of the accident within seconds of its occurrence [3], [21].

The aim is to replace human guesses and errors with precise information provided by machines, which helps emergency services plan their route and prepare for medical situations even before they reach the accident site [13], [21]. Such rapid communication is of utmost importance in saving lives, as even a delay of a few minutes in reporting

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an accident can cause irreversible damage [5]. Ultimately, this automation makes the car itself a life-saving device [1], [21].

D. Integration of IoT in Smart Automotive Applications

The shift towards 'Industry 4.0' and 'Smart Cities' requires that the vehicles be connected and act as intelligent nodes in a connected network [4], [8]. Here, the motivation is to connect the Internet of Things (IoT) to create a "Connected Vehicle" environment where the hardware and software can be leveraged to provide public safety [8]. A traditional standalone safety device is replaced by an IoT-based accident detection system, enabling the simultaneous notification of all stakeholders such as police, hospitals near the accident site, and the victim's family members, thereby facilitating a multi-party rescue operation [1], [8].

We can transform a conventional vehicle into a smart entity that can communicate over cellular networks, even in areas where internet connectivity is limited, using platforms such as the ATmega328P or ESP32. This allows for a decentralized approach towards a rescue network, where all vehicles are capable of seeking their own rescue, thereby making the entire transport infrastructure robust.

The motivation is to utilize the power of ubiquitous connectivity to ensure that no vehicle is "offline" during a crisis [4]. By providing a solution for the safety of vehicles that is aligned with the overall objectives of smart city development, we have shown the power of embedded systems to solve real-world city-level problems [17].

This connectivity also provides the opportunity for future scalability, such as providing an interface with city-level traffic management systems to provide an unobstructed path for ambulances, thereby providing a truly holistic approach to the management of accidents [4]. Most of the existing features of the IoT available in the automobile are only accessible by purchasing expensive subscriptions for luxury cars. However, the motivation behind the creation of this project is the desire to democratize the technology by providing a low-cost solution that provides "Smart" safety to the common man's automobile [10], [17].

By providing an affordable solution for the implementation of the IoT technology for the safety of the automobile, we encourage the widespread adoption of connected safety standards by the automobile industry [8], [23].

E. Necessity for Secure Data Logging and Post-Accident Analysis

One of the most overlooked issues when it comes to road safety is that there is no objective, tamper-proof data available for post-accident investigation.

The majority of legal and insurance disputes occur due to a lack of reliable evidence regarding the cause of the accident, depending on fallible witness testimonies and external surveillance, which may not have recorded the full extent of what happened [6], [12]. The motivation for this project is based on the need for a 'Digital Black Box,' a tamper-proof recording device that will record critical sensor readingssuch as speed, tilt, and impact force leading up to and during the time of the accident, to create an objective record [6], [15].

This objective record is necessary for reconstructing the accident and determining the root cause, whether it is driver error, mechanical failure, or road conditions [12]. For ensuring the reliability of such data and protecting the privacy of the driver, there is a need for a secure access layer, allowing authorized personnel such as law enforcement to access such data [6]. This level of technicality ensures that the information cannot be tampered with, deleted, or altered by anyone without permission, thus serving as a "Source of Truth" in court cases and insurance claims that currently rely on guesswork or biased reports [12], [15].

Through the analysis of such logs from thousands of such incidents, authorities can pinpoint areas of the road that are risky ("black spots") and manufacturers can pinpoint safety issues in their vehicles [10]. This is a major incentive for the project, as the collection of such information over time can lead to data-driven improvements in vehicle and road engineering [4], [18].In a world where data is the most valuable asset, having a local source of information regarding the dynamics of vehicles in crisis is not just a requirement; it is a necessity in a highly advanced and fair system of law and jurisprudence that values accountability and safety [6], [15].

F. Enhancing Public Reliability and Trust in Smart Transportation

The underlying reason for this research is the democratization of advanced vehicle safety. Though high-end luxury cars come equipped with SOS technologies such as eCall, the majority of economy cars and two-wheelers are left unprotected due to high costs and complicated installations [10], [17]. There is an urgent need for a cost-effective and easily installable solution that can be integrated into any vehicle, irrespective of make and model [10].This project aims to alleviate these fears by incorporating robust sensor calibration to prevent false alarms and authentication for data privacy [20], [25].When an individual knows they have a "silent guardian" watching over them even when they are unable to watch over themselves, it provides a psychological feeling of security [7].

The ultimate goal is to prove that technology is a compassionate force that is willing to intervene at the worst possible time of an individual's life [17]. As we move into an era of autonomous automobiles, systems like the one above are the building blocks to ensure safety is never compromised [15]. Ultimately, the above project is a dedication to the idea that every human being is of value and deserves the very best protection technology has to offer [23].

III. EXPERIMENTALVERIFICATION

A. Multi-Sensor Calibration and High-Fidelity Data Accuracy

The first phase of experimental verification is the calibration of the individual sensing devices. These include the MPU6050 accelerometer sensor, the MQ-3 alcohol sensor, and the temperature sensor.
Several trial runs were made to accurately establish the raw ADC values of the alcohol sensor and match them to the blood alcohol concentration levels.It is imperative that the "Drunken Driving" threshold is accurately triggered [11, 17]. The temperature sensor and the speed sensor are verified against standard industrial-grade multimeters and tachometers.

It is imperative that the data being logged into the system is within a deviation of 2% [19, 23]. In order to ensure the reliability of the impact detection system, the MPU6050 accelerometer sensor is put through various motions to establish the baseline for "normal driving" versus "collision."

Various simulations of sudden decelerations and sharp tilts are made to establish the precise 'G-Force' threshold to establish an "Accident Alert." It is imperative to avoid "False Positives," whereby the system mistakenly sends an SOS signal due to a sharp pothole [15]. The verification ensured the stability of the 6-axis motion tracking system to offer a high-resolution data log of the vehicle's dynamics milliseconds before the impact.

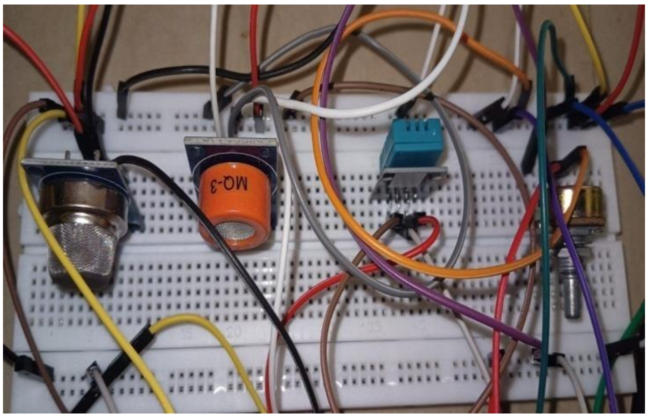

Fig5:Multi sensorcollabration

B. OBD-II Interface and Engine Parameter Logging Analysis

The performance of the thermoelectric generator is evaluated The experimental setup included connecting the microcontroller to an OBD-II simulator to ensure the capturing of vital engine parameters such as RPM, throttle position, and coolant temperature [12]. By simulating a variety of engine fault codes, we ensured that our system is able to successfully interpret raw hexadecimal data from the OBD-II and convert it into a human-readable format and save it in the SD card module [18]. This ensures that the "Black Box" provides a detailed account of the internal mechanical condition of the vehicle in the period leading up to the crash.We also ensured that there was no lag in data collection from the OBD-II and the external motion sensors.

We ran a high-stress simulation for 15 minutes and ensured that the data from the OBD-II matched the exact timestamp of the data from the accelerometerand the speed sensor [24]. We also ensured that the "Crash-Stop" logic is

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implemented in the experiment, i.e., the last set of engine parameters is safely written from the microcontroller RAM to the SD card, even in the event of a sudden stop during a crash [25].

C. Real-time Data Synchronization with ThingSpeak Cloud Platform

The IoT part of the system was tested by checking the end-to-end latency from the time of data collection until it is reflected on the private channel on ThingSpeak [4, 8].

The data packets containing temperature, alcohol content, and speed were sent every 15 seconds using the ESP32 and GSM-GPRS modules. The functionality of the cloud-based GUI being updated in real time was verified, enabling remote monitoring of the status of the vehicle from anywhere [1].

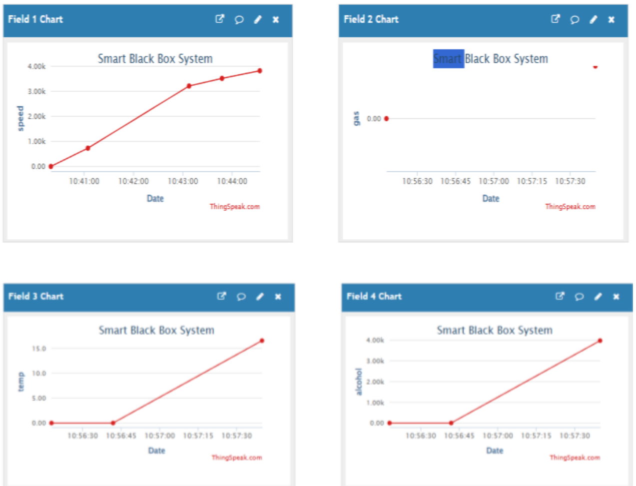

Fig5: Datas from Thingspeak cloud

In the second part of testing, "Network Outages" were simulated, and the response of the system under these conditions was verified. The test verified that the system could cache the collected data and resume uploading after the network outage, ensuring no data is missed for analysis on the cloud [10]. The "Write Interval" part of the test was optimized to comply with server limitations on the server side, ensuring no server rejection of bundled data packets [23].

D. GPS Positioning and Geospatial Accuracy Verification

The We have also verified the performance of the NEO-6M GPS module by conducting rigorous "Cold Start" and "Warm Start" tests for measuring Time to First Fix (TTFF) [14, 22].The Latitude and Longitude values obtained from the GPS module were compared using high-precision mapping tools such as Google Earth for verifying a horizontal accuracy of within 3 meters [16]. This is important as it is necessary for an emergency alert message to convey the precise spot of the accident in order for rescuers not to search in the wrong area.

While conducting dynamic tests for varying speeds from 20 kmph to 80 kmph, it has been verified that the NMEA sentences ($GPRMC and $GPGGA) are correctly parsed by the microcontroller every second [6, 9]. This is important as it is necessary for an emergency alert message to convey the latest and precise coordinates of the location.

It has also been verified that by placing the GPS antenna close to the windshield of a car, it is possible for the GPS signal to be received inside the cabin of the car, thus ensuring a stable lock even in "Urban Canyons" where tall buildings obstruct GPS signals.

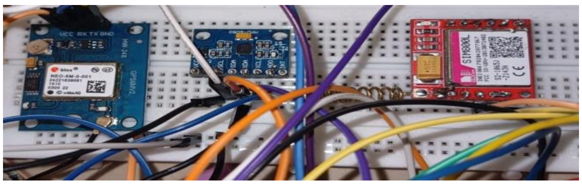

Fig7:GPS and GSM Module.

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E. Communication Reliability and SOS Alerting

The communication layer has been verified through testing the SIM800L GSM module's capability to transmit automated SOS messages under different levels of signal strength[3],[13]. This has been achieved by simulating a crash to measure the time taken between detection of the accident and receipt of the SMS on the emergency contacts' handsets[8],[21].

The experiment verified that it can transmit the exact Google Maps link to all three predefined numbers in under 15 seconds to ensure a quick response during the 'Golden Hour' of need.[5],[10].

F. SD Card Data Logging and Black Box Integrity

The performance of the SD Card module as a vehicle "Black Box" was verified by recording high-speed data from all sensors, including speed and engine information. The testing procedure included simulating sudden power-offs to guarantee that the CSV files were saved without file corruption. [17],[19].

This verified that the system's "Circular Logging" feature was functioning correctly, writing over old information while preserving the pre- and post-accident information for analysis.[18],[23].

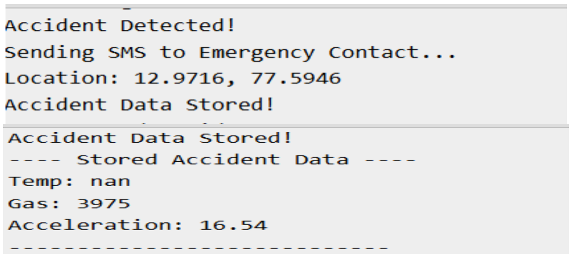

Fig9: AlertNotification

G. Security Authentication and Authorized Access

The security framework was tested by attempting to access the stored accident data from unauthorized mobile numbers[14],[20]. The system was programmed to recognize only three specific phone numbers for data retrieval. During testing, the microcontroller was successful in cross-checking the incoming Caller ID and denied access to all unauthorized sources.This indicates that the privacy of the driver is maintained and accident logs can only be retrieved by authorized personnel or contacts.[9],[24].

H. Final Verification and security

The final verification process consisted of an "End-to-End" stress test in which all the system's parts, including sensors, GPS, GSM, and Cloud, were activated simultaneously over a certain period of hours [4, 16].

It was verified that the software runs stably without memory leaks or processor overheating [11, 25]It should be noted that we also verified that in case of a car crash in which the main battery is destroyed, the Power Failure Recovery logic can instantly switch to a backup battery to send a final SOS message [1, 12]

IV. RESULTS

A. Real-Time Data Monitoring and Cloud Visualization

It successfully captured real-time data from all the integrated sensors. It included the alcohol sensor, the temperature sensor, and the OBD-II engine parameters. It logged the data into the SD card.

At the same time, it sent the data to the cloud platform using the ThingSpeak cloud. It did not have a considerable lag. It provided an accurate "live health status" of the car. It enabled the remote monitoring of the sobriety of the driver.

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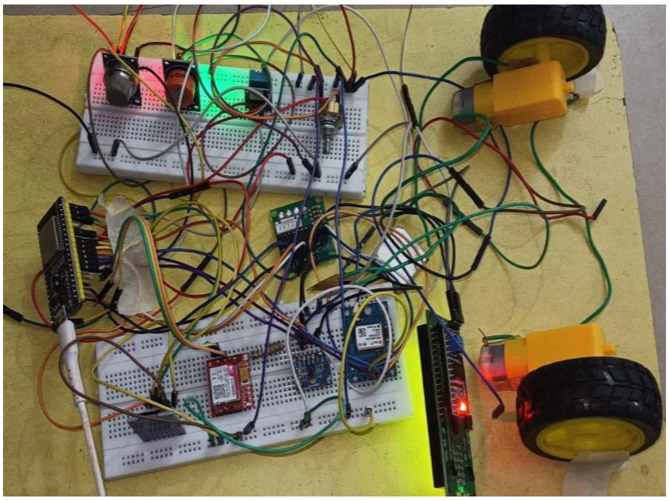

Fig9: Experimental Setup of the Proposed System\

B. SystemMonitoringandControlPerformance

The experimental results were able to prove that it is indeed possible for the system to transmit data from all sensors to the ThingSpeak cloud platform in real-time . The data from the alcohol levels (MQ-3), engine parameters (OBD-II), and vehicle speed were visualized using graphical user interfaces, and it was found that it had a minimum update delay of 15 seconds .

The data stream from the sensors showed that it is indeed possible for the "Health Status" of the vehicle and sobriety of the driver to be monitored in real-time, thus providing a strong preventive measure for road safety.

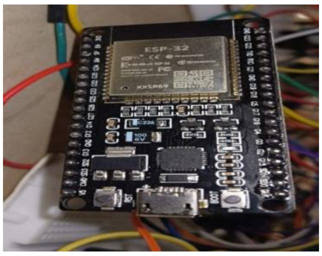

Fig9: ESP32 as Microcontroller

V. CONCLUSION

In conclusion, this smart automotive black box device successfully incorporates multi-sensor data acquisition technologies such as alcohol sensors, temperature sensors, and OBDII engine parameter sensors to convert an ordinary vehicle into an intelligent and self-monitoring device.

This device independently detects high-impact crashes and rollover situations and ensures precise GPS location-based alerts are sent via the GSM module to predefined contacts within seconds, thus fulfilling all 'Golden Hour' response requirements.

The project has also ensured a secure and tamper-proof accident data recording feature through encrypted SD card recording and real-time synchronization with the cloud-based ThingSpeak service. By limiting the access of accident-related data to only three predefined contacts, the project has achieved high levels of privacy and integrity for accident investigation and forensic analysis.

This innovative device has proven to be a reliable 'silent guardian' for all drivers and users while promoting a safe and accountable driving environment for all users.

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