Smart IoT Solution for Real-Time Crash Event Monitoring and Accident Reconstruction

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Abstract
In this research, we have created a real-time vehicle crash detection and safety system for enhancing road safety and emergency response. It uses the MPU6050 accelerometer/gyroscope for sensing crash impacts and rash driving, we have used GPS Neo6m module for tracking location, and the SIM800A GSM module for providing SMS alerts. When our device overcomes X-axis acceleration thresholds, it will count as a crash, and the system records critical data like —GPS coordinates, timestamps, and sensor values—to an SD card and sends an alert to emergency contacts through SMS. The system was tested by placing all these modules on a remote-control car with limited performance issues pertaining to network and GPS connectivity. It provides an affordable, scalable safety solution that is configurable to many types of vehicles and delivers both real-time emergency notification and post-crash data logging. Its open-source nature enables customization, and it is a potential platform for future technology innovations in smart and autonomous vehicles.

Keywords: Crash Detection, Vehicle Safety, Real-Time Monitoring, MPU6050, GPS Neo6m, SIM800A, Emergency Alert System, Rash Driving Detection, IoT-based Safety System, Smart Vehicle Technology

1. Introduction

Global road traffic accidents are a major cause of killing more than 1.35 million people every year. One of the major reasons for this staggering figure is the slow emergency response and false crash analysis after an accident. To address this issue, the inclusion of Internet of Things (IoT) technologies in automotive safety systems has come up as an effective measure to improve real-time crash identification and emergency alert systems.

IoT-based solutions take advantage of such components as GPS modules, accelerometers, gyroscopes, and GSM communication for identifying crashes, monitoring vehicle location, and sending SOS aterts. Accelerometers such as the MPU6050 are able to record changes in motion, which when combined with gyroscopic information and GPS points, can properly indicate crash occurrences. GSM modules also help in emergency messages.

But these current systems have limitations. False alarms based on aggressive driving, network connectivity issues, and absence of data storing facilities usually make them less effective and less reliable. Most current devices fail to record features like detection of rash driving, GPS tracing, GSM-based alerting, and offline storage of data—this arise a research gap in vehicle safety.

For these issues, this research puts forward an intelligent vehicle safety system that combines the MPU6050 sensor, GPS, GSM, and SD card modules. The system is intended to precisely identify accidents, save data offline, and provide real-time alerts through SMS so as to reduce false alerts and remain reliable even in low-network conditions. This methodology is centered on practical testing and technical implementation, providing a building block toward more intelligent transportation systems and enabling future improvements in autonomous vehicle safety.

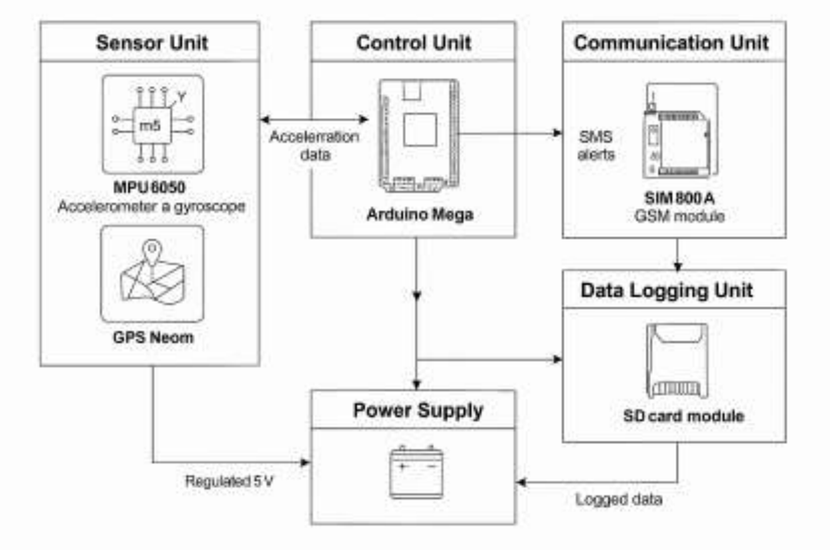

Fig 1: System Architecture Diagram

2. Literature Review

This project utilizes IoT to create an intelligent vehicle safety system incorporating alcohol testing, eye-blink sensors, and proximity alerts with GPS and GSM. It improves road safety and emergency response by avoiding accidents and sending crash sites in real time. [1]

This IoT system incorporates GPS, GSM, and in-built sensors to track location, alcohol content, drowsiness, and engine temperature in real-time. It increases safety of urban transport by sending SMS notifications, initiating onboard alerts, and supporting web-based tracking to avoid accidents and theft. [2]

This IoT-based accident response system uses shock sensors to detect crashes and instantly sends GPS location and victims' medical data to emergency services, reducing response times. It also provides data for road safety improvements, with plans for integration into vehicle manufacturing and government databases.[3]

This IoT-based vehicle security system employs RFID verification and GPS tracking through Arduino to ensure against theft and usage monitoring, demonstrating consistent performance during tests. Future work includes scaling it up for larger vehicles and enhancing GPS accuracy for better tracking. [4]

EDRs record detailed crash information that facilitates better accident investigations and safety research, even though there are initial expenses and legal issues with privacy and fault allocation. Standardization initiatives ensure greater adoption, and EDRs become a game-changer for highway safety once challenges are overcome. [5]

EDRs capture important vehicle information near crashes to assist with accident reconstruction and liability, with EU and U.S. mandates resulting in fewer fatal crashes and saving costs. Research indicates that EDRs encourage safer driving, decreased repair expenses, and significant economic and environmental benefits. [6]

3. Methodology

This section discusses the methodology used for designing, developing, and testing the vehicle crash detection and safety system, describing hardware integration, software development, and qualitative verification using real-time demonstrations.

1. System Design

The proposed system integrates various hardware components to enable real-time crash detection, location tracking, emergency communication, and data storage. The system employs an MPU6050 gyroscope and accelerometer sensor to sense abrupt collisions and changes in vehicle orientation, which are essential for the detection of rollovers or crashes. The GPS module will track location continually. And the GSM module provides SMS alerts with real-time gps location and other data to emergency contact. Also, an SD card module is used to store sensor data locally, so that data is not lost in the event of network disruption.

2. Hardware Integration

In the hardware part we have MPU6050 sensor, which records acceleration and orientation data, and communicates with the Arduino Mega 2560. At the same time, the GPS module and the GSM modules work in gathering location data and sending it over the internet.

An SD card module is used for storing data offline. For reliable performance, A detailed circuit diagram was designed for correct wiring and reliable power distribution to each module.

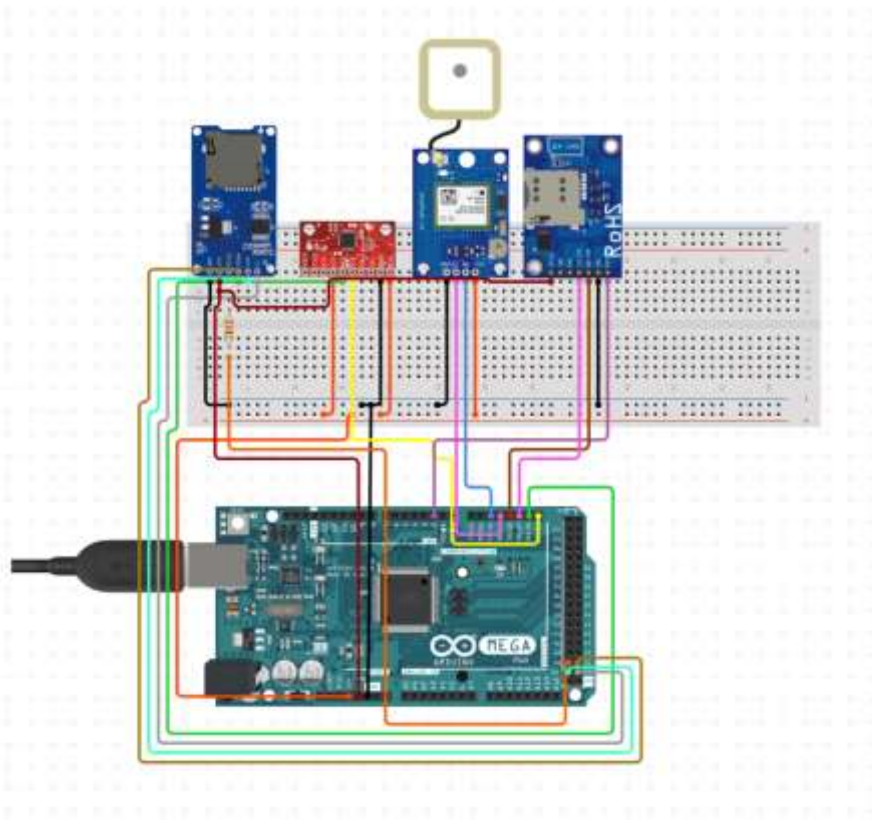

Fig 2. Circuit Diagram of our system.

3. Program Development

The program was created for monitoring, decision-making, and communication. The program reads X-axis acceleration values from the MPU6050 sensor to determine any sudden change, which is a sign of a crash or rash driving behavior. These values are matched against an established threshold to determine impact events.

Whenever an event occurs, the system starts. It first saves the corresponding sensor data, as well as GPS locations, to the SD card. In addition, an emergency SMS notification is sent through the GSM module to emergency contacts. This message provides important information such as the crash status and the real-time GPS location.

Besides automated notifications, the system also has incoming SMS commands. When a user sends a particular keyword such as "location", the system acts upon the request and returns the current location of the vehicle, providing real-time tracking functionality.

4. Data Flow and Communication Architecture

The system is constructed to facilitate real-time coordination between sensors, processing, storage, and communication units to provide effective functioning during normal driving and emergency situations.

- **Internal Data Flow**

There are two main sensors—MPU6050 (I2C) for orientation and acceleration, and GPS Neo6m (UART) for speed and location—that constantly feed data to the Arduino Mega 2560. The Arduino processes this data in real-time, comparing it against predefined safety thresholds to detect rash driving, crashes, or rollovers. When abnormal behavior is identified, relevant data is stored on an SD card via SPI.

- **External Communication Flow**

In case of a crash or rollover, the SIM800A GSM module sends an SMS containing GPS coordinates and optional sensor data to emergency contacts. The system also allows remote tracking; an SMS with a keyword like “location” gives signal to Arduino for sending vehicle’s current position and an SMS having current location is sent to the contact from which the “location” message is received.

- **Summary**

The system’s architecture follows a structured flow: sensor data is collected, evaluated in real-time, and either stored locally or used to send alerts, ensuring safety in all conditions.

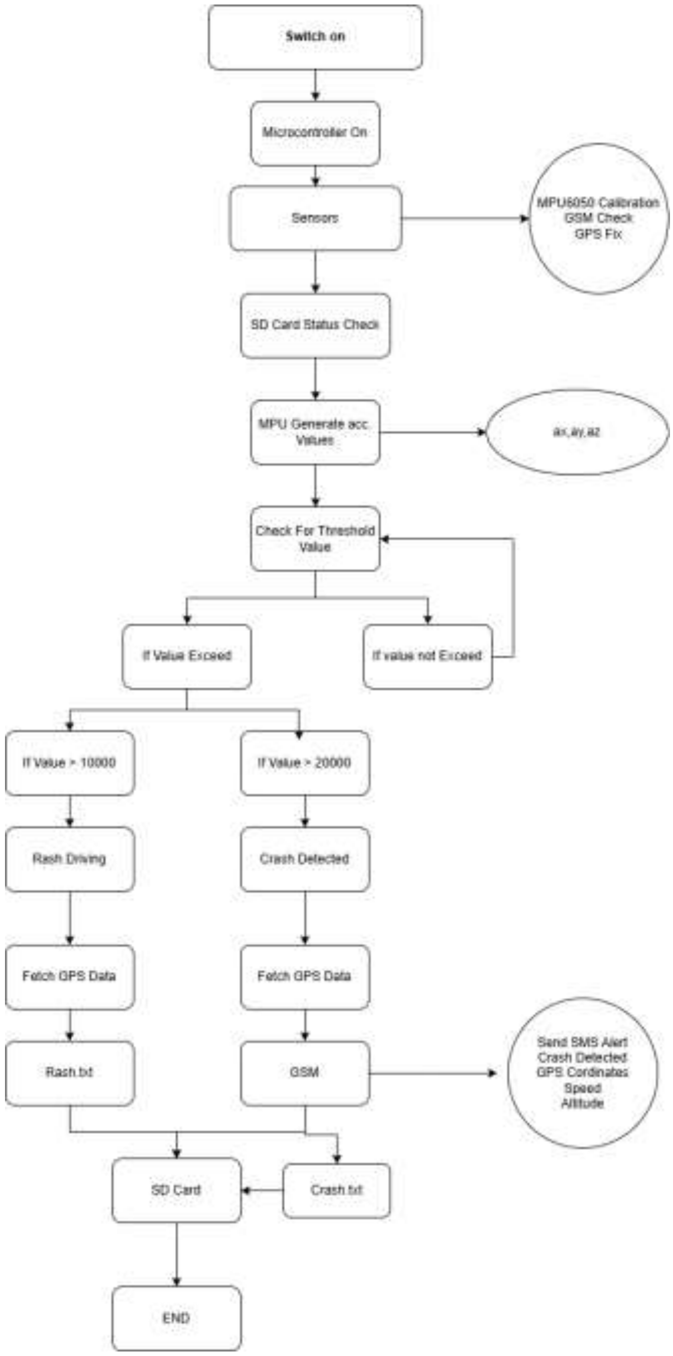

Fig: Data Flow Diagram

5. Qualitative Validation

The system's real-time performance was tested under controlled conditions. The successful receiving of live alerts on a mobile phone confirmed the functioning of the crash detection system and the transmission of SOS messages. Furthermore, the data stored on the SD card was thoroughly examined to ensure accurate logging of accelerometer and GPS readings during simulated crashes and rash driving scenarios.

To ensure seamless integration of software and hardware elements, system architecture and data flow diagrams were used, which provided a clear graphical overview of information exchange in the system. A circuit diagram detailed to the last detail was also referred to ensure proper hardware connections and smooth power supply through all modules. These verifications encompass live SMS alert screenshots, sensor data samples stored, and the relevant system diagrams. All these qualitative findings establish the effectiveness and reliability of the system in practice.

6. Limitations

- The research does not incorporate quantitative performance measures like accuracy rates, detection latency, or false positive rates.
- Additional research is necessary to obtain and evaluate quantitative data for thorough performance assessment.

7. Results and Discussion

The performance of the designed vehicle crash detection and SOS alert system was assessed via. a series of field tests and comparative study. The main aim was to confirm the validity and efficiency of the threshold calibration for detecting crashes. Another goal was to determine how reliable the SOS alert mechanism is, compared to the threshold calibration method using conventional safety systems.

- **Threshold Calibration and Validation:** Fixing a proper acceleration threshold is very important for proper crash detection. If the threshold is set too low, the system can produce false detections as a result of slight road irregularities like potholes or speed bumps. On the other hand, thresholds too high can lead to missed detections, for example, in low-speed crashes where deceleration will not be severe but dangerous, nonetheless. Therefore, threshold validation consists of testing under different driving conditions.
- Real-world testing included scenarios such as low-speed collisions, high-speed impacts, and emergency braking. During these tests, the system recorded X-axis acceleration data using the MPU6050 sensor. By analyzing this data, the impact threshold was fine-tuned to optimize. A balanced threshold value ensured that the system detected genuine crashes while avoiding alerts during non-critical disturbances. Also, we removed the rollover detection feature as it will mislead crashes.
- **SOS Alert System Performance:** After removing rollover detection, the SOS alert system focused exclusively on detecting significant deceleration along the X-axis. A crash was considered to have occurred when the absolute value of the X-axis acceleration (|ax|) exceeded 20,000. Upon detection, the system triggered an SMS alert containing GPS coordinates, a timestamp, and event details.

  Performance evaluation was conducted across different environments—rural, urban, and remote areas—to test GPS signal quality and network availability. In rural regions with clear satellite visibility and strong network signals, the system responded within 2 seconds, accurately sending alerts. In the case of partially satellite-covered cities and moderate traffic, the system still was able to send notifications in 3 seconds with reasonable GPS accuracy. Yet, in rural places where there is no network or GPS signal, even though the crash was registered, the alert didn't work because of lack of connectivity. This constraint highlights the need for stable GPS and mobile communication infrastructure for the best system performance.

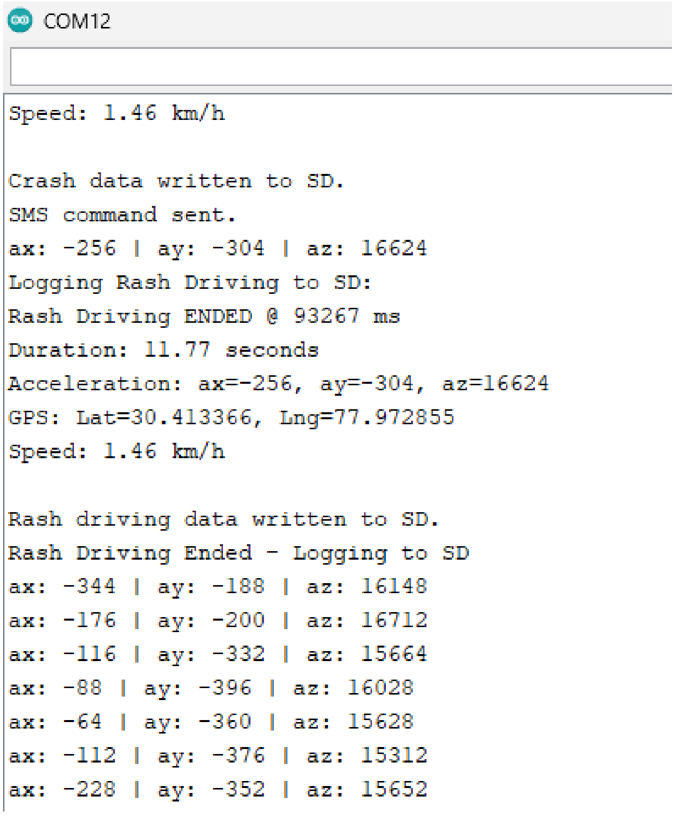

Figure 5.3: Crash and Rash Driving Data (Serial Monitor Output)

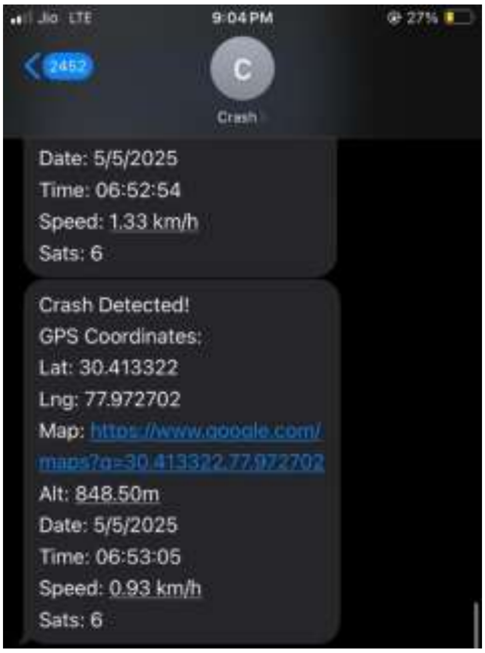

Figure 5.4: ***SOS Alert SMS Message with GPS Coordinates***

- **System Reliability and Metrics:** Four primary performance metrics tested the SOS system: reliability, timeliness, accuracy, and false positive rates. GPS accuracy was kept within a 10-meter window during urban testing. False positives were minimized through varying thresholds to exclude common road anomalies, thus enhancing user confidence and trust in the system.

To improve future performance, some optimizations are recommended. These are to integrate better-quality GPS modules with improved satellite coverage through dual-SIM or 4G-capable GSM modules for enhanced network stability.

- **Comparison with Traditional Systems:** The system suggested here has major benefits compared to traditional crash detection. Traditional systems like airbag deployment and onboard diagnostics (OBD-II) work mainly internally and do not support external communication. They are dependent on manual action to call emergency services and are generally restricted to onboard use.
  Whereas our system utilizes low-cost but effective hardware like the MPU6050 accelerometer, GPS module, and SIM800A GSM module. It measures real-time SMS notifications to predefined emergency numbers, hence constituting an independent safety solution. In addition, the system saves useful crash-related information such as acceleration, GPS coordinates, and timestamp into text files for subsequent post-crash analysis, useful for insurance cases and legal purposes.

Feature	Existing Systems	Proposed System
Crash Detection	Relies on airbag sensors or vehicle diagnostics (in-vehicle only).	X-axis acceleration threshold detection, ensuring more reliable and accurate crash detection.
Post-Crash Data Logging	Limited or no data logging available.	Logs data in .txt format: accelerometer readings, GPS coordinates, and event timestamps.
SOS Alerting	Emergency services contacted manually.	Automatic SOS alerts via SMS with GPS location, timestamp, and event details.
External Communication	Limited to vehicle's internal system (some vehicles).	Real-time SMS alerts to predefined contacts via the SIM800A GSM module.
Location Accuracy	Limited GPS, typically in higher-end models.	Uses GPS Neo6m for real-time location tracking and precise GPS coordinates.
Threshold Calibration	Limited ability to adjust thresholds.	Customizable thresholds for crash detection (X-axis acceleration) to fit specific vehicle conditions.
Cost and Accessibility	Often expensive or proprietary solutions.	Low-cost, open-source, and accessible to a wide range of vehicles.

Table 5.1 summarizes the key differences between traditional and proposed systems, highlighting advances in detection quality, alerting delivery, data storage, and cost

- **Advantages and Use Cases:** The proposed crash detection system has many possible uses. It can tell when someone is driving too fast or braking too hard, which can be dangerous. Also, the system can keep detailed crash data, which makes it possible to do thorough investigations after an accident. This data-driven method of looking at accidents and keeping an eye on driver behavior can help both insurance companies and individual car owners. The system is cheap, has a customizable threshold, and doesn't depend on the car makers, which makes it good for a lot of different kinds of cars. This solution makes advanced features available to all vehicle owners, unlike proprietary systems that are only available on high-end models.

8. Conclusion and Future Possibilities

- **Summary of Findings**

The car safety and crash detection system designed in this project is intended to enhance safety on the highway through monitoring of accidents, rollover, and reckless driving, while also providing instant contact with emergency numbers.

Accelerometer-based crash recognition mechanisms were accurate in identifying high impact accidents. Specific acceleration thresholds on the X-axis ($|ax|>20000$) were used to distinguish between normal operating conditions and crash scenarios. This calibration significantly reduced the incidence of false positive sides and ensured that small roads such as potholes and speed breakers did not cause false warnings.

From the perspective of emergency communications, the SOS alert mechanism showed reliable performance by forwarding SMS messages within seconds after a crash. These messages, including location coordinates and timestamps, were usually sent within 2-3 seconds, but delays were discovered in areas with poor reporting on mobile networks. The GPS module showed high accuracy under clear conditions, but performance was degraded in areas with attractive visibility of satellites, such as tunnels and urban canyons.

Data storing has become an effective component, recording accelerator meter data, GPS coordinates, and timestamps in an accessible format for post-crash analysis. This feature improves the value of your system during accident investigations and insurance claims. However, certain restrictions have also been identified. In particular, the need for a stable power supply for the SIM800A module has been identified. This was originally resolved by dedicating a separate power source. Furthermore, instability in gyroscope measurements excluded takeover detection, although initially seen.

The success of the project was strongly based on calibration of appropriate thresholds to ensure meaningful crash recognition. The communication modules in the system worked best in areas with high coverage but had to struggle in remote locations. This indicates that future iterations can benefit from integration of modules into 4G/5G or dual network functions. Overall, these findings highlighted the effectiveness of the system and shed light on opportunities for improvement.

- **Contributions of the Project**

This project provides a meaningful contribution to road safety by providing open source and inexpensive solutions for vehicle crash detection and real-time emergency response. The systems created here are very affordable. And works on a wide variety of vehicle models including older and less expensive ones.

Real-time emergency communications are present as a vital innovation. When it detects a crash, the system sends a detailed alert with location and timing data. This will help in getting emergency services quickly. This might be helpful in situations where the driver is not able to respond.

The recorded data not just for legal and insurance reports, but also for the analysis of behavior, especially when used in fleet management environments where monitoring driver surveillance behavior is vital. The ease of data format (.txt or CSV) guarantees compatibility with minimal data tools as well as better accessibility.

The second significant contribution is how adaptable the system is with extensible crash recognition thresholds. This is a characteristic that enables the system to be configured across various classes of vehicles and driving environments to enhance accuracy and minimize false alarms. Moreover, the autonomy of our own vehicle system systems guarantees broad applicability without enforced limitations through closed platforms and manufacturer limitations.

- **Recommendations for Future Work**

The main future area to explore is to reinstate detection. Employing the gyroscope data of the MPU6050, a more calibrated and stable approach can be constructed to correctly detect vehicle overturns, which are dangerous and need emergency action.

Further, the functionality of GPS modules can be enhanced by incorporating a switch over to high-profit antennas or multi-constellation GNSS receivers supporting alternative satellite systems like GLONASS and BeiDou. This enhances location accuracy in areas where satellite signals are poor.

Extension of the system to multiple sensor inputs like brake pressure, steering angle, and proximity sensors can create a more micro view of the dynamics of pre-crash. This not only enhances accuracy but also gives insight into why accidents happen that can affect earlier techniques. Furthermore, the shift from offline data storage to cloud-based monitoring can offer real-time insight in car conditions. The cloud, supported with Wi-Fi, 4G or 5G modules, can enable fast data analysis and instant access to crash procedures.

We can also use algorithms for machine learning to predict uncertain driving behavior. By analyzing acceleration patterns, braking and revolution, the system can provide predictive warnings and promote safe driving habits through continuous feedback.

We can also integrate the system into On-Board Diagnosis (OBD-II), it will help in monitoring vehicle health. Actual warnings related to problems such as braking failures and tire pressure abnormalities allow preventive maintenance and reduce the risk of accident-related mechanical failures.

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