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Rider Safety Device with Real-Time Accident Alert System

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KEYWORD

Accident Detection, ESP32, MPU6050, Sensor Fusion, GPS, GSM, IoT, Road Safety.

ABSTRACT

Road traffic accidents, especially those involving two-wheelers, are a major safety concern in developing countries like India. A large number of deaths occur due to delays in providing timely medical assistance after accidents. Quick response during the critical "Golden Hour" can significantly increase the chances of survival, but many accidents remain unreported due to lack of immediate communication. To solve this problem, this paper presents a smart rider safety device that automatically detects accidents and sends emergency alerts in real time. The system is based on an ESP32 microcontroller integrated with an MPU6050 sensor, which combines an accelerometer and gyroscope to detect abnormal motion using sensor fusion techniques. The system identifies accident conditions by analyzing sudden impact and abnormal tilt, reducing false detections during normal riding. Once an accident is detected, the system obtains the location using a GPS module and sends an alert message through a GSM module, including a Google Maps link for easy tracking. A fail-safe feature is also included, allowing the rider to cancel the alert within a short time if no serious accident has occurred. The proposed system is low-cost, reliable, and can be easily installed on existing vehicles. Experimental results show that it provides accurate detection and fast alert transmission, making it a practical solution for improving road safety and emergency response.

1. Introduction

Road traffic accidents have become one of the leading causes of death worldwide, particularly in developing countries like India. Two-wheeler riders are among the most vulnerable road users due to limited physical protection and high exposure to risk factors such as overspeeding, poor road conditions, and lack of safety measures [1]. A significant number of fatalities occur not only because of the severity of the accident but also due to delays in providing timely medical assistance. One of the most critical concepts in trauma care is the "Golden Hour," which refers to the first hour after an accident during which immediate medical treatment can significantly increase the chances of survival [2]. However, in many real-world situations, this crucial time is often lost due to the absence of immediate communication, lack of awareness among bystanders, or accidents occurring in remote

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areas. The concept of emergency response during the “Golden Hour” is illustrated in Fig. 1.
Traditional accident reporting systems rely heavily on human intervention, which makes them unreliable and time-consuming. In many cases, victims are unable to call for help due to injuries or unconsciousness. This highlights the need for an automated system that can detect accidents and instantly notify emergency contacts without any manual effort.

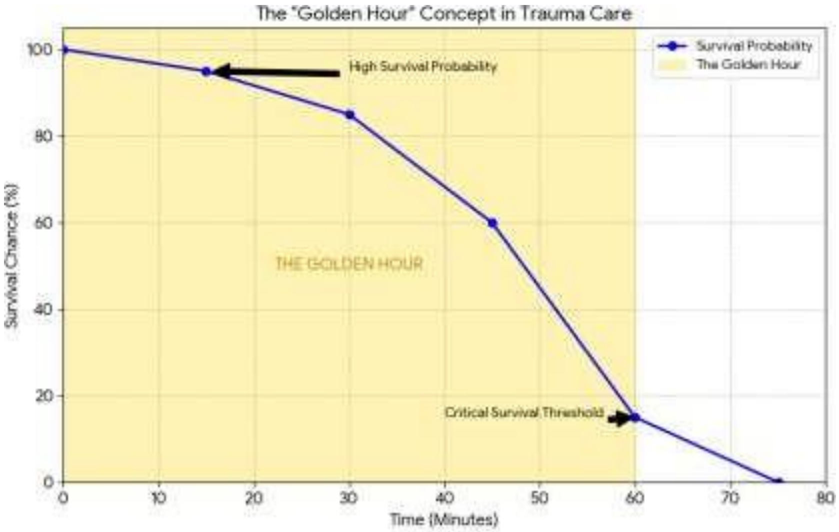

Figure 1: The “Golden Hour” Concept in Trauma Care (adapted from authors’ project report)

With advancements in embedded systems and sensor technologies, it is now possible to design intelligent safety systems that can monitor vehicle conditions in real time. Sensors such as accelerometers and gyroscopes can detect sudden impact and abnormal tilt, which are key indicators of an accident [4].
In this paper, a smart rider safety device is proposed that uses an ESP32 microcontroller along with an MPU6050 sensor for accurate accident detection through sensor fusion. The system is capable of identifying accident conditions and sending emergency alerts along with location details using GPS and GSM technologies. Additionally, a fail-safe mechanism is included to prevent false alerts, improving system reliability and user trust [12]. The proposed system aims to reduce response time, improve communication efficiency, and enhance overall road safety by providing a practical and cost-effective solution.

2. Literature Review

Accident detection and alert systems have been widely studied in recent years due to the increasing number of road fatalities. Various approaches have been proposed using different sensing and communication technologies. These systems can be broadly categorized based on their detection mechanisms and communication methods.
Early systems primarily relied on **accelerometer-based detection**, where sudden spikes in acceleration were used to identify accidents [5]. Although these systems are simple and cost-effective, they often produce false positives due to road irregularities such as potholes or speed breakers. Additionally, they may fail to detect low-impact accidents where no significant acceleration spike is observed.
Another approach involves the use of **mechanical tilt sensors**, which detect the inclination of the vehicle during a fall. These systems are effective in identifying tilt conditions but are limited in their ability to detect impact-based accidents. Moreover, mechanical components are prone to wear and tear, reducing long-term reliability.
To overcome these limitations, modern systems use **sensor fusion techniques**, combining accelerometer and

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gyroscope data for more accurate detection. The MPU6050 sensor, which integrates both functionalities, has been widely used in research for detecting both impact and tilt conditions simultaneously [4]. This approach significantly reduces false alarms and improves detection accuracy.

In terms of communication technologies, earlier systems used **2G GSM modules** to send SMS alerts [6]. While these systems are simple and reliable, they are becoming obsolete due to the gradual phase-out of 2G networks. More recent systems utilize **4G/LTE-based modules**, which provide better reliability and future compatibility.

Some modern solutions also rely on **smartphone-based applications**, which use built-in sensors for accident detection. However, these systems are unreliable as they depend on the phone being properly positioned and functional during the accident.

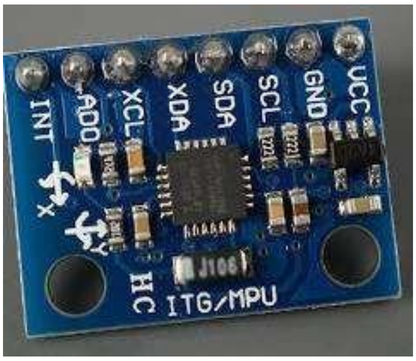

Figure 2: MPU6050 6-DOF Sensor Module (adapted from authors' project report)

Despite these advancements, many existing systems either lack accuracy, are too expensive, or depend heavily on user interaction. Additionally, very few systems include a **fail-safe mechanism** to prevent false alerts, which is an important factor for user trust and system reliability [12].

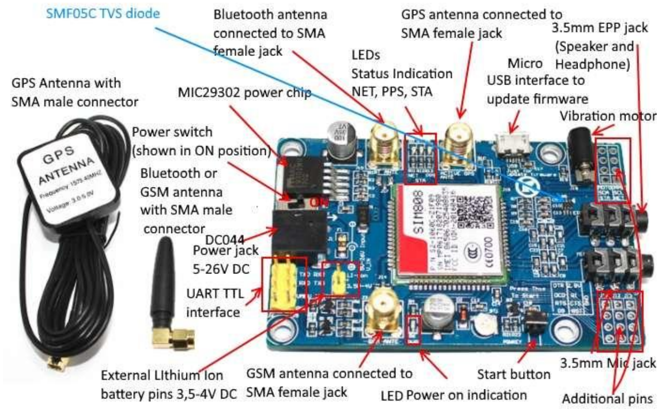

Figure 3: SIM7600 4G/LTE GSM Module (adapted from authors' project report)

Therefore, there is a clear need for a system that is accurate, cost-effective, reliable, and capable of automatic operation without human intervention. The proposed system addresses these gaps by integrating sensor fusion, real-time communication, and a fail-safe alert mechanism.

3. Proposed System

The proposed system is designed to automatically detect accidents and send emergency alerts without requiring any human intervention. It integrates sensing, processing, and communication modules to ensure real-time

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detection and response. The overall working principle of the system is illustrated in Fig. 4.

The system is built around an ESP32 microcontroller, which acts as the central processing unit. It continuously monitors data from the MPU6050 sensor, which combines a 3-axis accelerometer and a 3-axis gyroscope to detect motion and orientation [4]. By applying sensor fusion techniques, the system can accurately identify abnormal conditions such as sudden impact and excessive tilt. The block diagram of the system architecture is shown in Fig. 5.

The system consists of the following major components:

1. **Sensing Unit**

The MPU6050 sensor is used to measure acceleration and angular velocity. It detects sudden changes in motion and tilt angle, which are key indicators of an accident. The use of both accelerometer and gyroscope improves accuracy and reduces false detections.

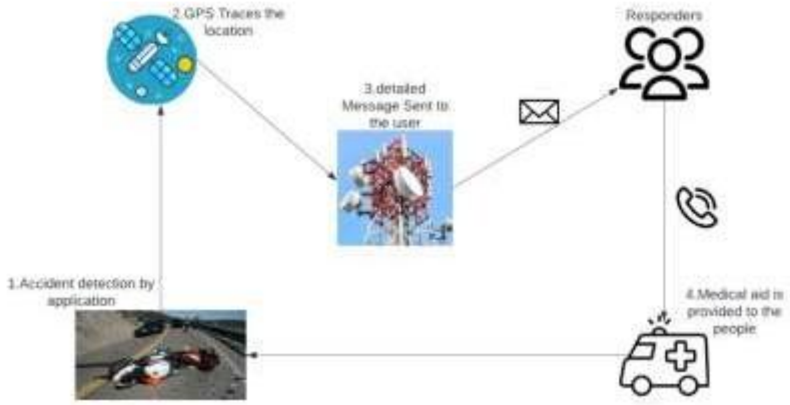

Figure 4: High-Level Working Principle of the System (adapted from authors' project report)

2. **Processing Unit**

The ESP32 microcontroller processes the sensor data and executes the accident detection algorithm. It evaluates whether the detected motion exceeds predefined thresholds for impact and tilt.

3. **Communication Unit**

A GSM module (SIM7600) is used to send emergency alerts via SMS [6]. The message includes the accident notification along with a Google Maps link containing the exact location of the incident.

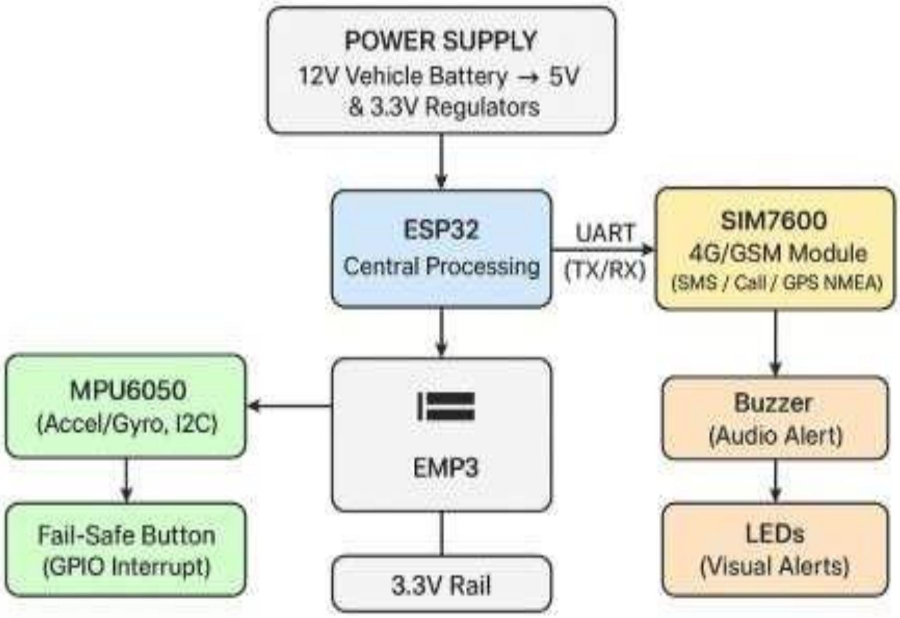

Figure 5: Block Diagram of the System Architecture (adapted from authors' project report)

4. Location Tracking

A GPS module is used to obtain real-time geographical coordinates. These coordinates are embedded in the alert message to help emergency services reach the accident location quickly.

5. Alert and Safety Mechanism

The system includes a buzzer and a fail-safe cancel button. When a potential accident is detected, the buzzer is activated to alert the rider. If the rider is safe, they can press the cancel button to stop the alert. Otherwise, the system automatically sends the emergency message after a short delay [12].

Figure 6: Fail-Safe Cancel Button (adapted from authors' project report)

6. Power Supply Unit

The system is powered using the vehicle's battery, with voltage regulators ensuring stable power supply to all components.

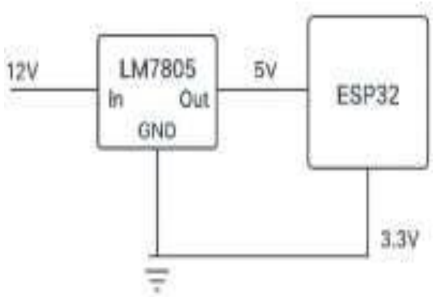

Figure 7: Power Supply Circuit Diagram (adapted from authors' project report)

The integration of these components results in a fully automated system capable of detecting accidents and sending alerts in real time. The proposed system is cost-effective, reliable, and can be easily installed on existing two-wheelers, making it suitable for practical deployment.

4. System Architecture

The system architecture of the proposed rider safety device is designed in a modular manner to ensure efficient data processing, real-time monitoring, and reliable communication. The architecture consists of sensing, processing, communication, and alert modules, all coordinated by a central microcontroller. The overall block diagram of the system architecture is shown in Fig. 8.

At the core of the system is the ESP32 microcontroller, which acts as the main control unit. It continuously receives data from the MPU6050 sensor using the I2C communication protocol. The MPU6050 measures both acceleration and angular velocity, enabling the system to detect sudden impacts and abnormal tilt conditions [4].

The detailed circuit connections of the system are illustrated in Fig. 9.

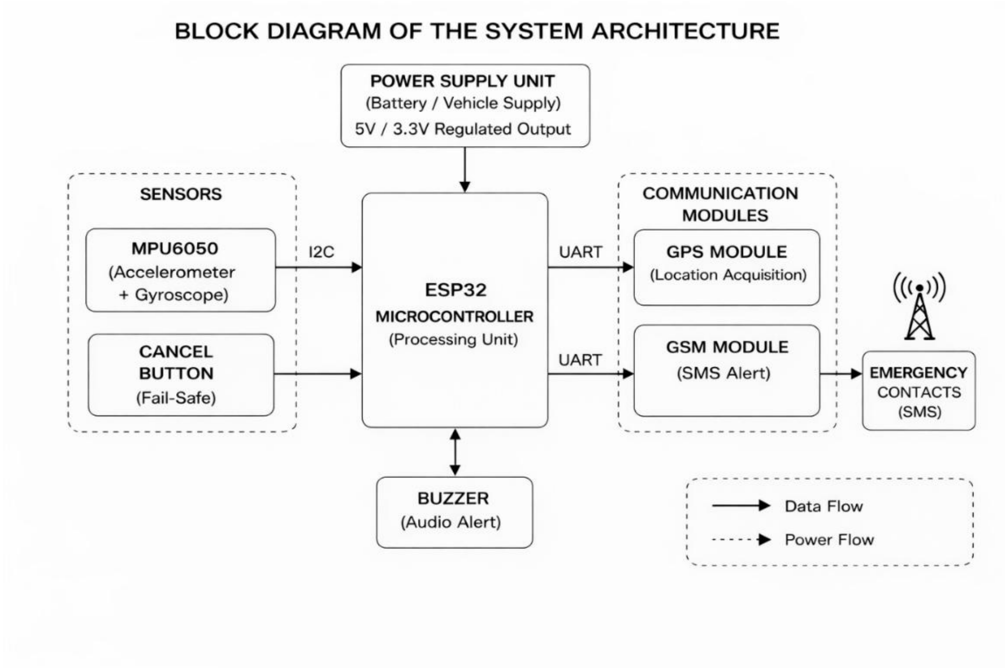

Figure 8: Block Diagram of the System Architecture (adapted from authors' project report)

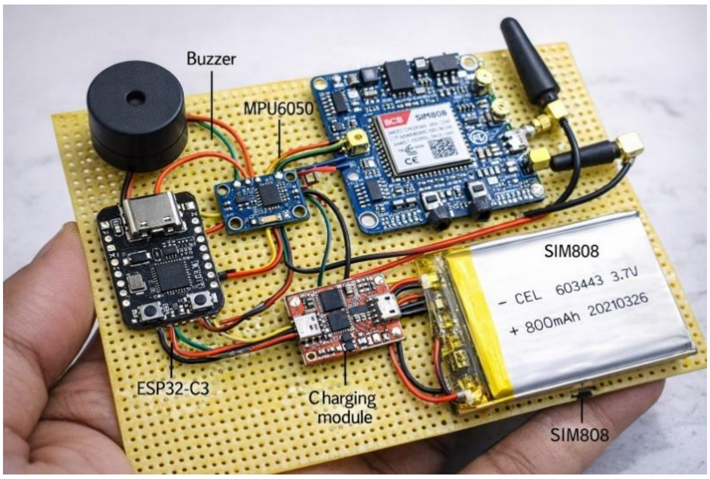

Figure 9: Detailed System Circuit Diagram (adapted from authors' project report)

The system uses multiple communication interfaces for efficient operation. The MPU6050 sensor communicates with the ESP32 via I2C, while the GSM and GPS modules communicate through UART serial interfaces. This allows simultaneous handling of sensor data and communication tasks. The ESP32 pin configuration used for interfacing different components is shown in Fig. 10.

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Figure 10: Pinout Diagram of ESP32 WROOM-32 Module (adapted from authors' project report)

The architecture also includes a power supply unit that converts the vehicle's battery voltage into regulated 5V and 3.3V outputs required by different components. This ensures stable operation of the system under varying conditions.

Additionally, a fail-safe mechanism is integrated into the system through a tactile push button, allowing the rider to cancel false alerts. The buzzer provides an audible warning before sending the emergency message.

Overall, the system architecture ensures seamless interaction between hardware components, enabling accurate accident detection and rapid communication. The modular design also allows easy scalability and future enhancements.

5. Methodology

The methodology of the proposed system defines the step-by-step process used to detect accidents and send emergency alerts in real time. The system follows a structured workflow that integrates sensor data acquisition, decision-making, and communication. The complete operational flow of the system is illustrated in Fig. 11.

5.1 Data Acquisition

The system continuously collects real-time data from the MPU6050 sensor. This sensor provides acceleration and angular velocity values along three axes, which are used to determine the motion and orientation of the vehicle [4]. The data is transmitted to the ESP32 microcontroller using the I2C communication protocol.

5.2 Accident Detection Algorithm

The accident detection is based on a combination of impact and tilt analysis using sensor fusion techniques.

(a) Impact Detection

The system calculates the resultant acceleration using the following relation:

$$R = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

If the resultant acceleration exceeds a predefined threshold (e.g., 3g), the system considers it as a potential impact.

(b) Tilt Detection

The tilt angle is calculated using accelerometer data. If the tilt angle exceeds a certain threshold (typically 60°–70°), it indicates that the vehicle has fallen.

(c) Decision Logic

An accident is confirmed if:

- A high impact is detected, OR
- A significant tilt is sustained for a short duration

This dual-condition approach helps in reducing false positives caused by normal riding conditions such as sudden braking or sharp turns.

5.3 Alert Activation

Once an accident is detected, the system activates a buzzer to alert the rider. A short delay (e.g., 10 seconds) is provided during which the rider can cancel the alert if it is a false trigger.

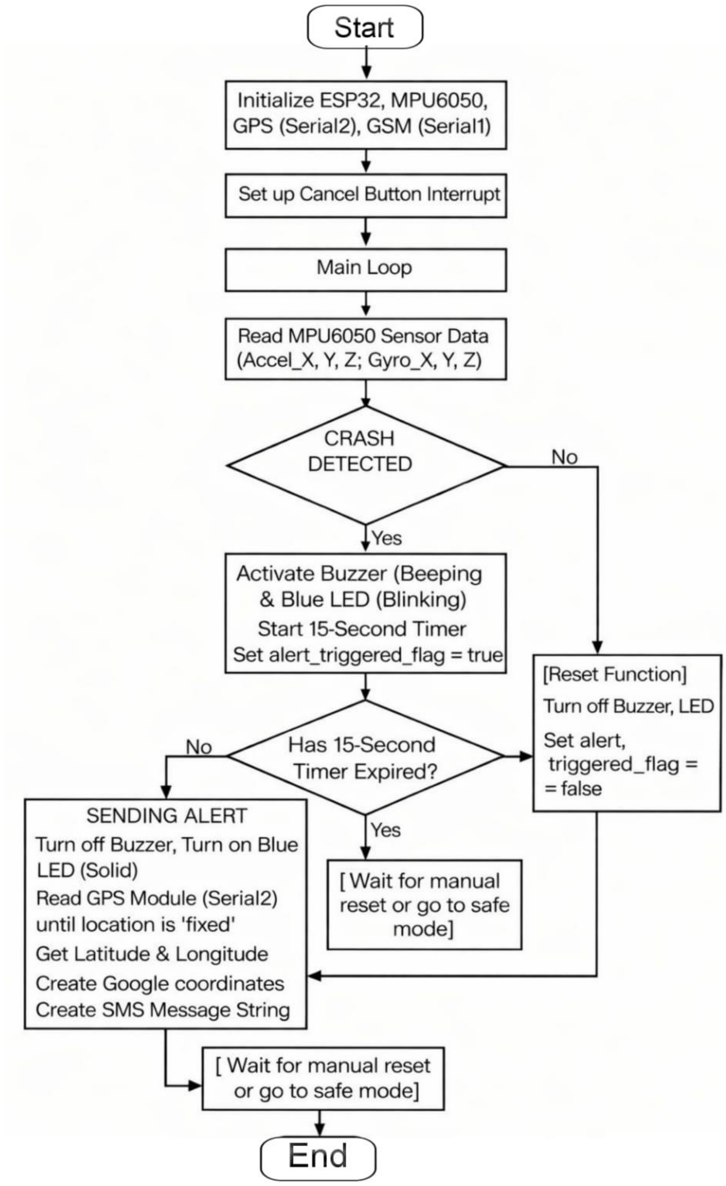

Figure 11: System Operational Flowchart (adapted from authors' project report)

5.4 Fail-Safe Mechanism

A tactile push button is used as a cancel switch. If the rider presses the button within the given time window, the alert process is stopped. This feature improves system reliability and prevents unnecessary emergency alerts [12].

5.5 Location Acquisition

If the alert is not canceled, the system retrieves the current geographical location using a GPS module. The latitude and longitude values are obtained and formatted into a Google Maps link for easy navigation.

5.6 Alert Transmission

The system uses a GSM module to send an emergency SMS to predefined contacts. The message includes:

- Accident alert notification
- Location link

This ensures that emergency services and relatives can quickly reach the accident site [6].

5.7 System Workflow Summary

The overall process can be summarized as follows:

1. Continuous monitoring of sensor data
2. Detection of impact and tilt
3. Activation of alert system
4. Fail-safe cancellation option
5. GPS location retrieval
6. SMS transmission via GSM

6. Results and Discussion

The proposed rider safety system was tested under various real-world conditions to evaluate its performance in terms of accuracy, response time, and reliability. The testing included scenarios such as sudden impact, vehicle fall, and normal riding conditions.

6.1 Accident Detection Performance

The system successfully detected accident conditions based on predefined thresholds for impact and tilt. When subjected to sudden shocks or falls, the MPU6050 sensor accurately captured abnormal motion data. The use of sensor fusion significantly reduced false detections compared to systems using only accelerometers [4].

During normal riding conditions such as braking or minor bumps, the system did not trigger false alerts, demonstrating the effectiveness of the dual-condition detection logic.

6.2 Alert Transmission and Response Time

Once an accident was detected and not canceled by the user, the system successfully retrieved GPS coordinates and transmitted an emergency alert message via the GSM module. The average time taken for alert transmission was found to be minimal, ensuring quick communication with emergency contacts [6].

The alert message included a Google Maps link, which allowed easy navigation to the accident location. This feature enhances the efficiency of emergency response.

6.3 Fail-Safe Mechanism Evaluation

The fail-safe cancel button was tested under different conditions to verify its effectiveness. The system provided a short time window during which the rider could cancel the alert. This feature successfully prevented false alerts in situations where no actual accident occurred [12].

6.4 System Reliability

The system demonstrated stable performance during continuous operation. The ESP32 microcontroller efficiently handled sensor data processing and communication tasks without significant delay. The integration of multiple modules worked seamlessly, ensuring reliable system behavior.

6.5 Discussion

The results indicate that the proposed system provides a balance between accuracy, cost, and reliability. Compared to traditional systems, it offers automatic detection and real-time alerting without requiring human intervention.

However, certain limitations were observed. The system depends on GSM network availability for sending alerts, and GPS accuracy may be affected in enclosed environments. Despite these limitations, the system performs effectively under normal conditions and provides a practical solution for accident detection and emergency response.

7. Advantages

The proposed rider safety device offers several significant advantages over traditional accident detection and reporting systems. One of the primary benefits of the system is its ability to automatically detect accidents without requiring any human intervention. This ensures that even if the rider is unconscious or unable to communicate, the system can still initiate an emergency alert. The real-time alert mechanism further enhances the effectiveness of the system by immediately sending notifications to predefined contacts, thereby reducing the delay in providing medical assistance.

Another major advantage of the system is its high detection accuracy achieved through the use of sensor fusion techniques. By combining data from both the accelerometer and gyroscope, the system can accurately differentiate between normal riding conditions and actual accident scenarios, thereby minimizing false alarms [4]. In addition, the integration of a GPS module enables precise location tracking, allowing emergency responders to quickly reach the accident site.

The inclusion of a fail-safe mechanism in the form of a cancel button further improves system reliability by giving the rider an opportunity to stop the alert in case of false triggering [12]. Moreover, the system is designed to be cost-effective and easy to install, making it accessible for a wide range of users without requiring major modifications to existing vehicles.

Furthermore, the compact design of the device ensures convenient placement on the vehicle, while the use of the ESP32 microcontroller provides flexibility for future enhancements such as IoT integration, cloud connectivity, and mobile application support. Overall, the proposed system reduces dependency on human intervention, improves response time, and provides a practical and scalable solution for enhancing road safety.

8. Conclusion

This paper presents the design and development of a smart rider safety device capable of automatically detecting accidents and sending emergency alerts in real time. The proposed system effectively addresses the critical issue of delayed emergency response, which is one of the major causes of fatalities in road accidents, especially in two-wheeler scenarios. By utilizing an ESP32 microcontroller along with an MPU6050 sensor, the system accurately detects accident conditions through sensor fusion techniques that analyze both impact and tilt [4].

The integration of GPS and GSM modules enables the system to transmit precise location details to predefined contacts, ensuring quick and efficient communication during emergency situations [6]. Additionally, the inclusion of a fail-safe cancel mechanism enhances system reliability by reducing false alerts and improving user trust [12]. The system operates autonomously, eliminating the need for manual intervention and making it highly effective even when the rider is unable to respond.

Experimental observations indicate that the system performs reliably under various conditions, providing accurate detection and rapid alert transmission. The proposed solution is cost-effective, easy to install, and suitable for real-world implementation. Overall, this work contributes to improving road safety by offering a practical and scalable accident detection and alert system that can significantly reduce response time and help save lives.

9. Future Scope

The proposed rider safety device provides a strong foundation for further enhancements and technological advancements. In future, the system can be improved by integrating machine learning algorithms for more intelligent and adaptive accident detection. Instead of relying on fixed threshold values, a trained model can

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analyze real-world riding data to improve accuracy and further reduce false detections.

The system can also be extended by incorporating IoT-based cloud integration, allowing real-time data storage and remote monitoring. This would enable the creation of a centralized database for accident records, which can be useful for analysis and improving road safety measures. Additionally, a dedicated mobile application can be developed to provide users with features such as live tracking, emergency contact management, and system configuration through Bluetooth or internet connectivity.

Further improvements can include the integration of additional sensors such as heart rate monitors or impact sensors to assess the physical condition of the rider after an accident. The system can also be miniaturized and embedded into a smart helmet, which would provide more accurate detection of head impact and improve overall safety.

Moreover, advanced communication technologies such as 4G/5G and cloud-based alert systems can be incorporated to enhance reliability and ensure faster data transmission. Features like automatic vehicle immobilization after a severe crash and integration with emergency services can also be explored.

Overall, the system has significant potential for future development, making it more intelligent, connected, and capable of providing enhanced safety solutions for riders.

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