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IoT based Motorcycle Accident Detection and Alert System

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ABSTRACT: Motorcycle travel remains the most hazardous mode of transportation worldwide. Unlike enclosed vehicles such as cars and buses, motorcycles leave riders directly exposed to their surroundings, lacking any protective frame to prevent serious injuries during accidents. To address this vulnerability, it becomes essential to implement a system capable of automatically detecting crashes and promptly notifying emergency services.

This paper presents a motorcycle crash detection and alert system designed to tackle this issue. The system employs an MPU6050 accelerometer and gyroscope sensor to continuously monitor the motorcycle's motion and orientation. When a crash occurs, a sudden change in tilt or acceleration is detected, indicating a possible accident. An ESP32 microcontroller processes this data and connects to the internet via the rider's mobile hotspot. Crash information, along with the motorcycle's location (obtained through the mobile phone's GPS), is uploaded to a Firebase real-time database. A companion mobile application fetches the crash status from Firebase and sends notifications to pre-registered emergency contacts, including the accident's time and location details. Additionally, the app features a false alert mechanism, giving the rider an opportunity to cancel notifications in non-critical scenarios. By immediately informing emergency services after an accident, this system has the potential to significantly reduce response times and save lives. Furthermore, the proposed solution is scalable and adaptable for integration into other vehicles and critical safety systems.

KEYWORDS: ESP32, MPU6050, Vibration Sensor

I. INTRODUCTION

The **Internet of Things (IoT)** refers to a network of interconnected devices equipped with sensors, embedded systems, and communication modules that collect and exchange data with minimal human intervention. Originating from an early concept introduced by Kevin Ashton in 1999 during his time at Procter & Gamble, IoT has now evolved into one of the most impactful and widely adopted technologies in areas ranging from smart homes and industrial automation to healthcare and transportation. An IoT system typically comprises intelligent devices embedded with sensors and processors that gather information from their surroundings. This data is transmitted—either to the cloud or processed locally—via an IoT gateway or hub. These devices can communicate among themselves and respond to real-time events, often functioning autonomously. In many modern implementations, IoT solutions are enhanced with machine learning and AI capabilities to improve the accuracy, speed, and decision-making potential of the system.

In the context of motorcycle crash detection, IoT plays a vital role by integrating sensors like the MPU6050 accelerometer and gyroscope, a vibration sensor, and a Wi-Fi-enabled ESP32 microcontroller. These components work together to monitor motion parameters in real time. When unusual acceleration, tilt, or vibration is detected, the ESP32 sends the event data to a Firebase Realtime Database over a wireless network. A companion mobile application continuously retrieves this data, and if a crash is confirmed, it automatically notifies emergency contacts with the motorcycle's location.

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II. LITERATURE REVIEW

The **Smart Helmet System** is designed to enhance safety and situational awareness for motorcyclists [1]. It offers a practical solution for riders who prioritize protection and convenience. Although proximity sensing in vehicles is a well-established concept used in several research works and commercial solutions, the smart helmet system builds on this foundation by refining the design to maximize efficiency and user benefit.

This system is developed with an emphasis on improving advantages seen in prior implementations while minimizing typical drawbacks. Key benefits of this system include:

- Easy access to all necessary components.
- Fully automated operation, requiring no user intervention.
- User-friendly and straightforward to operate. However, the system also has certain limitations:
- The use of relays may result in higher power consumption.
- It involves a one-time initial investment for setup and hardware.

Despite these minor drawbacks, the integration of such Intelligent systems-especially those involving automatic braking and impact sensing—has the potential to significantly reduce accident rates and save lives.

The adoption of **intelligent braking systems** has the potential to significantly reduce the number of road accidents and save countless lives [2]. Much like seat belts, these systems are increasingly seen as essential safety features in modern vehicles. By minimizing the risk of injury, they serve as a long-term investment in vehicle safety. Advanced braking technologies act as a comprehensive safety measure, often integrating multiple features that help prevent collisions and safeguard passengers by working as part of a unified vehicle safety system.

Advantages of smart braking systems include:

- They help avoid wheel lock-up, allowing the rider to maintain balance and control.
- These systems reduce stopping distance, which is crucial in minimizing the severity of crashes.
- They decrease the impact of high-speed collisions by initiating timely deceleration. However, some challenges are associated with this technology:
- Smart braking systems increase the overall cost of the vehicle due to added components.
- The maintenance cost is higher, as wheel sensors used in the system are expensive and require recalibration if misaligned or damaged.

An effective device that can instantly relay crash location details to nearby emergency services is crucial for ensuring timely assistance.[3] Numerous researchers have explored the development of automated accident detection and alert systems, incorporating technologies such as smartphones, GSM modules, GPS tracking, vehicle-to-vehicle communication networks (VANETs), machine learning techniques, and dedicated mobile applications. To enhance road safety, all vehicles should ideally be fitted with systems capable of autonomously detecting accidents and communicating vital information.

Key benefits of such systems include:

- A significant reduction in fatalities resulting from traffic accidents due to faster response times.
- The ability to track and locate stolen vehicles accurately through GPS technology. However, the system also has certain limitations:
- The controllers used can be expensive, increasing the system's cost.
- Integrating additional components like cameras can further raise the overall expense.

Despite these drawbacks, the integration of such systems is a valuable step toward making roads safer and enhancing emergency responsiveness.

III. PROPOSED METHOD

Problem Statement

Motorcycle transportation remains one of the riskiest modes of travel across the globe. Data from the National Highway

Traffic Safety Administration (NHTSA) reveals that motorcycles account for approximately 212.7 fatalities per 100 million vehicle miles traveled, making them significantly more hazardous than other vehicles. Despite advancements in safety measures over the years, motorcycle-related deaths still make up a large portion of road fatalities.

In 2019, motorcycles represented just 3% of registered vehicles in the United States but were involved in 14% of all traffic- related deaths. Additionally, around 84,000 motorcyclists suffered injuries in that same year. The inherent vulnerability of motorcycles—due to their open design—makes them particularly dangerous, although using helmets and practicing defensive riding can reduce the risks. A common and deadly scenario involves vehicles making left turns in front of oncoming motorcycles, which accounted for nearly half of the fatal crashes involving both cars and motorcycles in 2019.

This project introduces a smart system for motorcycle crash detection and emergency alerting. Its primary objective is to detect when a crash has occurred, verify whether it is genuine (not a false alert), and send a notification containing the crash location and timestamp to a preconfigured emergency contact. This enables faster emergency response and can assist people nearby in providing timely help.
The system uses an MPU6050 sensor, which includes a gyroscope and accelerometer, to detect sharp movements or a fall, suggesting a crash. Once such a motion is detected, the system updates the crash status in the Firebase Realtime Database. A connected mobile application then retrieves this status, fetches the current GPS coordinates, and sends an SMS alert to the designated contact. In the event of a false alert, the rider can press a cancel button within a specific time window to stop the message from being sent.

Objectives

- Leverage the MPU6050 sensor's multi-axis accelerometer data to identify potential motorcycle crashes by detecting instances where the vehicle has fallen or lost stability.
- Integrate a false alert cancellation feature that enables the rider to dismiss the alert if they are unharmed or if the crash detection was triggered incorrectly.
- Implement an automatic notification system that informs the rider's pre-saved emergency contact about the detected crash, prompting them to take appropriate action.
- Aim to minimize emergency response time by transmitting accurate GPS coordinates and crash timing, ensuring timely assistance reaches the accident location.

Architecture Diagram

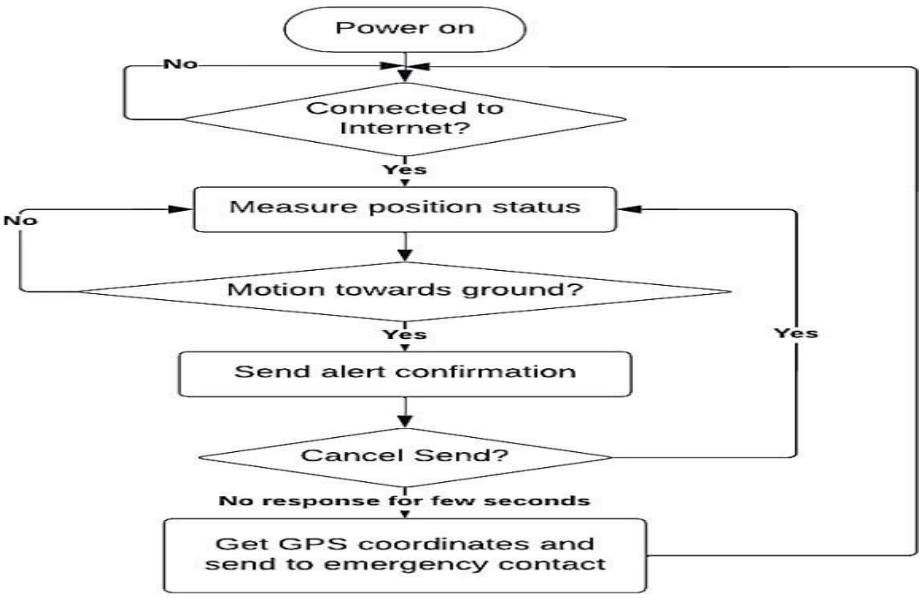

Fig. 1. Architecture diagram

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1. **System Initialization:** The crash detection system is powered on when the motorcycle is started. The ESP32 module is automatically activated. Internet access is essential for uploading sensor data and retrieving user-specific threshold values stored in Firebase.
2. **Connecting to the Internet:** The ESP32 connects to Wi-Fi through the rider's mobile hotspot. These hotspot credentials are configured during the initial setup process. Once paired, the system continues to use the phone's network to communicate with the Firebase Realtime Database.
3. **Reconnection Attempts:** If the ESP32 fails to connect to Wi-Fi, it periodically checks the connection every 30 seconds. If the connection still fails, the ESP32 resets itself and restarts the connection sequence, ensuring continuous attempts until a successful internet link is established.
4. **Monitoring Motorcycle Orientation:** Upon successful connection, the ESP32 begins reading motion data from the MPU6050 accelerometer and gyroscope sensor and vibration sensor. Simultaneously, the mobile app uses the built-in GPS to fetch the bike's live location, which is updated periodically (e.g., every 60 seconds). The MPU6050 tracks the x and y tilt movements, and their combination is used to detect abnormal orientation (e.g., toppling or falling), which signals a potential crash.
5. **Crash Identification:** A crash is detected when the change in acceleration and vibration between consecutive readings exceeds predefined thresholds. Under normal riding conditions, Firebase is regularly updated with the status as "inActive". When a sudden motion exceeding the threshold is observed, the status is updated to "Active" to indicate a potential crash. This triggers the mobile application to take further action.
6. **False Alert Mechanism:** When the crash status switches to "Active", the mobile app displays a prominent "False Alert" button and initiates a 10-second countdown. During this time, sensor updates are paused to prevent multiple alerts from being triggered by the same crash event. A notification also alerts the rider with a warning to cancel the alert if it's not a real emergency.
7. **User Cancels Alert:** If the rider presses the "False Alert" button within the 10-second window, the status is reset to "inActive" in Firebase, and no emergency alert is sent. This helps prevent unnecessary alerts in case of false positives or minor incidents.
8. **No Response from Rider:** If the rider does not respond within the 10-second period, the app assumes an emergency and sends an SMS to the preconfigured emergency contacts. This SMS includes the message "Crash Detected" along with the live Google Maps location of the incident. After sending the alert, the system resets its status and resumes normal sensor monitoring.

IV. IMPLEMENTATION OF THE SYSTEM

Requirements for Software and Hardware
Software Requirements

Kodular App: Kodular is a free and user-friendly platform that enables individuals to create mobile applications without the need for extensive programming knowledge. It employs a drag-and-drop interface, allowing users to visually design their app's user interface and functionality by arranging pre-built components and blocks.

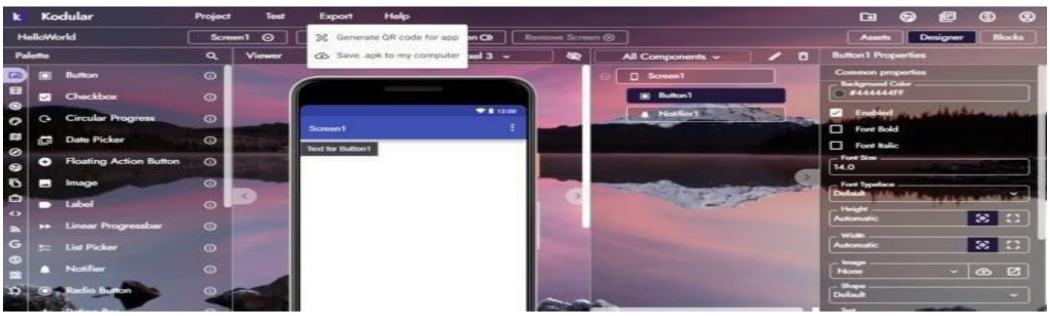

Fig. 2. Kodular Interface

- **Firebase Database:** Firebase Database is a cloud-hosted NoSQL database provided by Google as part of the Firebase platform, offering real-time data synchronization and robust backend services for web and mobile applications.
- **Arduino IDE:** The Arduino Software (IDE) is an open-source integrated development environment designed specifically for writing, compiling, and uploading code to Arduino-compatible microcontroller boards. It provides a user-friendly interface and a simplified programming language based on Wiring, making it accessible to both beginners and experienced developers.

Hardware Requirements

• **ESP32 Wi-Fi Module:** The ESP32 Wi-Fi module, shown in Figure 1, developed by Espressif Systems, stands as a cornerstone in the realm of wireless connectivity for embedded systems and Internet of Things (IoT) applications. Leveraging the ESP32 microcontroller chip's powerful dual-core processor and integrated Wi-Fi capabilities, this module offers a versatile solution for connecting devices to local networks and the internet.

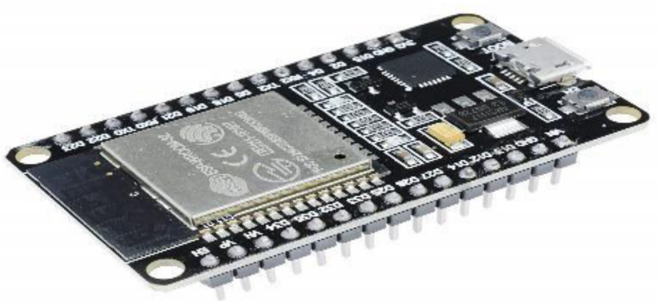

Fig. 3. ESP32 Wi-Fi Module

• **Vibration Sensor:** It detects and measures vibrations or oscillations in machines, structures, and environments, allowing for early detection of abnormalities, faults, or potential failures. Vibration sensors operate based on different principles, including piezoelectric, piezoresistive, capacitive, and MEMS offering a range of sensitivity, frequency response, and durability.

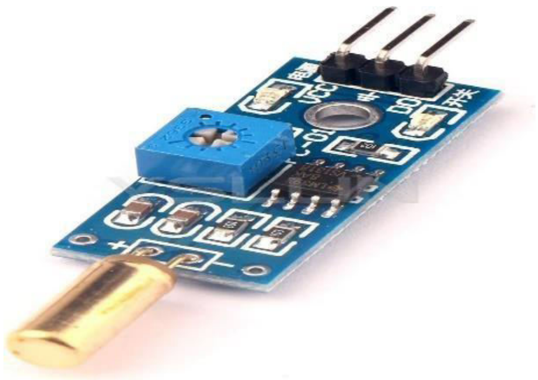

Fig. 4. Vibration Sensor

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• **MPU6050**: It is a fundamental component in the field of motion sensing and inertial measurement. Designed to detect changes in acceleration along one or more axes, it provides vital information about the movement, orientation, and vibration of an object or system. Accelerometers operate on various principles, including piezoelectric, capacitive, and Micro Electro Mechanical Systems (MEMS), each offering unique advantages in terms of sensitivity, size, and power consumption.

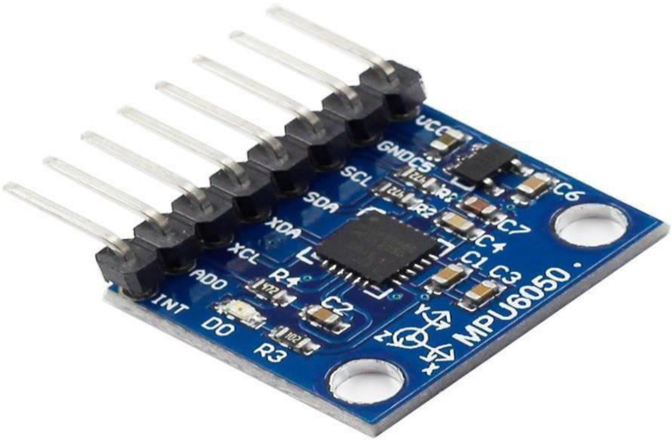

Fig. 5. MPU6050 Sensor

Connections:

1 Connecting ESP32 to MPU6050 (I2C Communication)

MPU6050 Pin	ESP32 Pin
VCC	3.3V
GND	GND
SCL	GPIO 22
SDA	GPIO 21

2 Connecting ESP32 to Vibration Sensor (SW-420)

Vibration Sensor Pin	ESP32 Pin
VCC	3.3V or 5V
GND	GND
DO (Digital Output)	GPIO 4

Fig. 6.Connections from MPU6050 and Vibration Sensor to ESP32 Module

Modules and description

This paper is implemented in a total of five modules. The five modules are

1. Sensor Setup and Configuration
2. Firebase Integration.
3. Calibration of Threshold Values.
4. Mobile app integration using kodular.
5. Testing and Deployment.

Module 1: Sensor Setup and Configuration

In this phase, the **ESP32** is programmed using the **Arduino IDE** to interface with the **MPU6050** sensor and Vibration Sensor. The sensors captures acceleration values along the X, Y, and Z axes and vibration values in real time. These values are displayed via the Serial Monitor and plotted using the Serial Plotter to visualize motion behavior during riding or crash events.

Key Features:

- Capture and display acceleration readings on all three axes.
- Graphical representation of motion on Serial Plotter.
- Fetch crash threshold values from **Firebase Realtime Database** (based on bike type).
- Evaluate motorcycle posture using accelerometer data.
- Transmit current posture status (e.g., "Active") to Firebase.

Libraries Used:

- MPU6050.h: Interfaces directly with the MPU6050 to retrieve accelerometer and gyroscope data.
- Wire.h: Enables I2C communication with SDA and SCL lines on ESP32-compatible boards.

Module 2: Firebase Integration

In this stage, the ESP32 is programmed to connect to Firebase through the rider's mobile hotspot. It retrieves threshold limits and uploads real-time crash data.

Main Functions:

- Establish Wi-Fi connection using predefined credentials.
- Automatically retry connection if Wi-Fi fails within a 10-second timeout.
- Read acceleration and vibration thresholds for the selected bike type from Firebase.
- Send crash detection status, along with sensor data, to the Firebase Realtime Database.

Module 3: Calibration of Threshold Values

In this module, calibration and testing were performed to determine optimal values for crash detection. After extensive trials, it
was observed that a threshold of 0.7g provided over 95% accuracy for typical crash patterns. These values can be updated remotely from the app, allowing different thresholds for Scooter, Commuter, and Sportsbike categories.

Module 4: Mobile App Integration using Kodular

This module involves creating a companion mobile application using Kodular, which acts as the interface between Firebase and the rider.

App Features:

- **GPS Location Tracking**: The app captures the phone's current coordinates every 60 seconds and stores it in Firebase.
- **Status Monitoring**: The crash status is updated in real time from Firebase and displayed to the rider.
- **Threshold Management**: Allows dynamic retrieval of crash threshold values based on selected bike type.
- **False Alert Feature**: A false alert button appears if a crash is detected, giving the user 10 seconds to cancel the alert and reset the posture to "Upright."

Timers are used in Kodular to fetch crash status and GPS every 1 second and 60 seconds respectively.

Module 5: Testing and Deployment

Once the full system was deployed, the thresholds were tested under various road conditions and crash simulations for all three bike types. The mobile app's interface allowed quick switching between vehicle types and verified accuracy under different speeds and angles.

The collected thresholds were fine-tuned and stored in Firebase as:

- **Scooter**: Low vibration, moderate acceleration.
- **Commuter**: Moderate vibration and acceleration.
- **Sports bike**: Higher tolerance values due to performance handling.

These values can be retrieved by the ESP32 automatically based on user selection from the app interface.

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V. RESULT

Kodular Interface: The mobile app, designed using Kodular, provides a user-friendly interface for the motorcycle crash detection system. It includes blocks for push notifications, crash alerts, and displaying the motorcycle's real-time location.

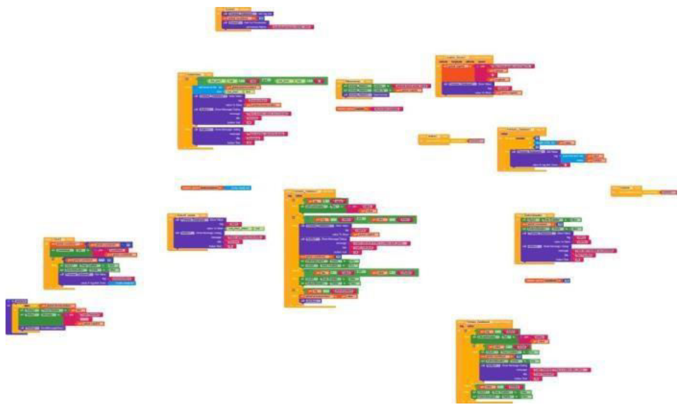

Fig .7. Kodular Interface

Mobile App Interface:

The screen indicates where users can save emergency contacts, set accelerometer and vibration sensor threshold values, and choose the bike type. The interface also includes a button to dismiss false alerts and update settings accordingly.

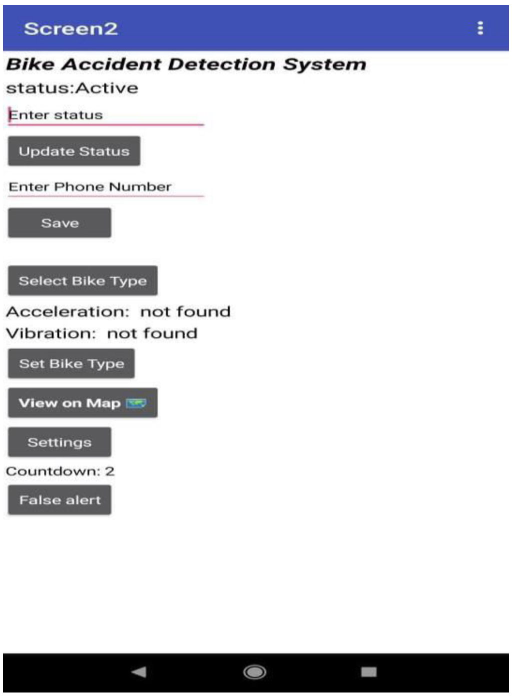

Fig .8. App Interface

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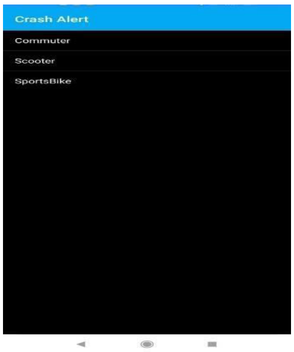

Fig. 9 .Selection of Bike

Firebase Interface: In this project, Firebase serves as the cloud platform for storing and updating real-time data. It stores the accelerometer and vibration sensor values, along with their threshold values, and the type of motorcycle. Firebase ensures seamless synchronization and quick updates of the sensor data for real-time analysis.

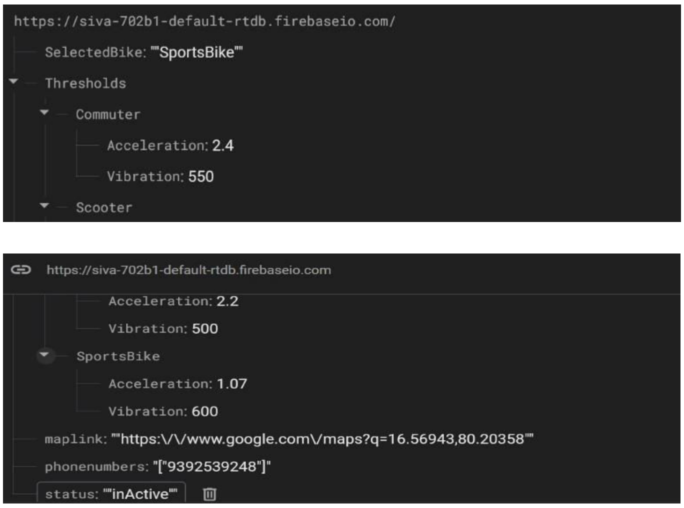

Fig .10. Firebase Interface

VI. FINAL OUTPUT

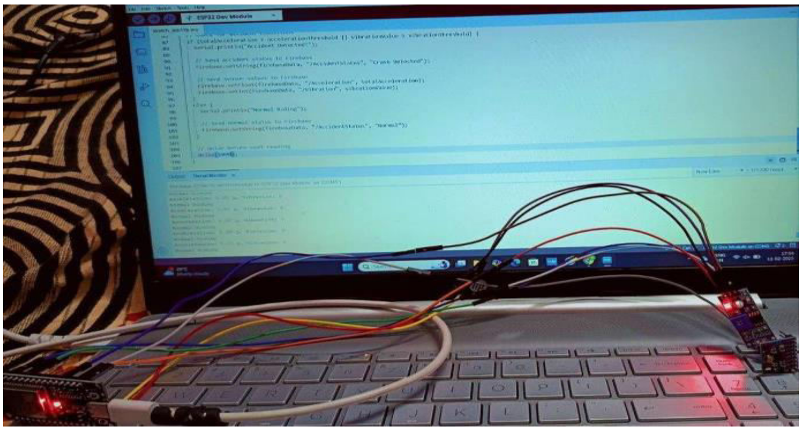

Fig .11. Final Experimental Setup

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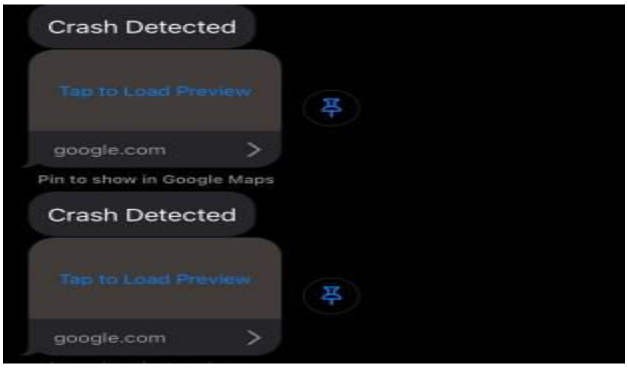

Fig. 12. Message in the Mobile Phone after crash occur

VII. CONCLUSION

In the context of road safety, particularly for motorcycles, IoT offers an impactful solution. Motorcycle accidents often lead to fatalities due to the delay in emergency response, not necessarily due to the severity of the crash itself. Riders, in the event of a collision, may be disoriented or physically incapacitated, making it difficult to call for help. Furthermore, if the crash occurs in a secluded or sparsely populated area, there's no certainty that passersby will intervene. In some cases, even in crowded places, bystanders may hesitate to get involved or might not recognize the severity of the situation. This delay in action can be life- threatening.

To address this, our project presents a smart crash detection and alert system using the MPU6050 sensor and ESP32 microcontroller. The system continuously monitors the motorcycle's motion to detect any abnormal activity, such as sudden tilt or acceleration change, indicative of a crash. In such an event, the system immediately updates the status to a cloud-based Firebase Realtime Database.

A mobile application, built with Kodular, reads this crash status and automatically fetches the rider’s GPS coordinates. To ensure no false alarms, a “False Alert” button appears in the app, giving the user a 10-second window to cancel the emergency notification. If unacknowledged, the system proceeds to send an SMS with the crash details and location to the stored emergency contact numbers. This proactive system not only ensures immediate notification of emergency services but also supports location tracking, making rescue operations faster and more efficient. The app can be further enhanced to store multiple contacts or intelligently send alerts to the nearest available contact using geolocation data. Such improvements will make accident response even more effective and could potentially save many lives.

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