END-SEMESTER REPORT

DEVELOPMENT ENGINEERING PROJECT (CP301)

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Finally, we humbly attribute our perseverance and achievements to the Almighty, whose grace guided us through challenges. This journey has reinforced our commitment to leveraging technology for societal good, and we eagerly anticipate future opportunities to advance safety solutions.

1. Title of the Project

Smart Helmet for Accident Detection

2. Abstract

In recent years, road accidents involving two-wheeler riders have emerged as a critical safety concern, particularly in countries like India where motorcycles constitute a major portion of daily transportation. Timely medical attention is often hindered due to the lack of immediate accident detection and communication. This project presents the development of a low-cost, standalone Smart Helmet system capable of detecting accidents and autonomously notifying pre-registered emergency contacts with precise location details. The helmet integrates an ADXL345 3-axis accelerometer, which monitors the rider's motion and detects abnormal impacts. Upon accident detection, the system utilizes a SIM900A GSM module and a NEO-6M GPS module to acquire the geographical coordinates of the incident and transmit them via SMS to family members, police, or emergency services.

The system is powered by a compact 12V battery, controlled via an on/off switch, and assembled on a breadboard with an Arduino Uno acting as the central microcontroller. Unlike existing smart helmet systems dependent on IoT, cloud servers, or mobile apps, this prototype is designed to work efficiently in remote locations without internet access, ensuring reliability in real-world conditions. The proposed solution emphasizes affordability, simplicity, and life-saving efficiency, contributing to smarter road safety for motorcyclists.

3. Introduction

Road traffic accidents remain one of the leading causes of death globally, particularly among two-wheeler users. In densely populated and vehicle-congested regions like India, motorcycles and bicycles serve as affordable and accessible modes of transportation, yet their riders face high vulnerability on roads. The World Health Organization and national safety boards consistently emphasize the alarming rise in fatalities related to two-wheelers, where delayed accident detection and lack of immediate communication with emergency services remain critical issues.

According to the National Safety Council (NSC), **1,377 preventable deaths** occurred due to bicycle-related incidents in 2023, marking a **53% increase over the past decade**. Of these, **937 deaths** were due to motor-vehicle collisions, while **440** occurred in other types of incidents. Notably, males accounted for **89%** of all fatalities—demonstrating a significant demographic at risk. Moreover, accident data reveals a seasonal trend: **deaths peak in warmer months**, especially from **July to October**, with **October recording the highest monthly toll of 156 deaths**, while **February had the fewest at 81** (*Figure 3.1*).

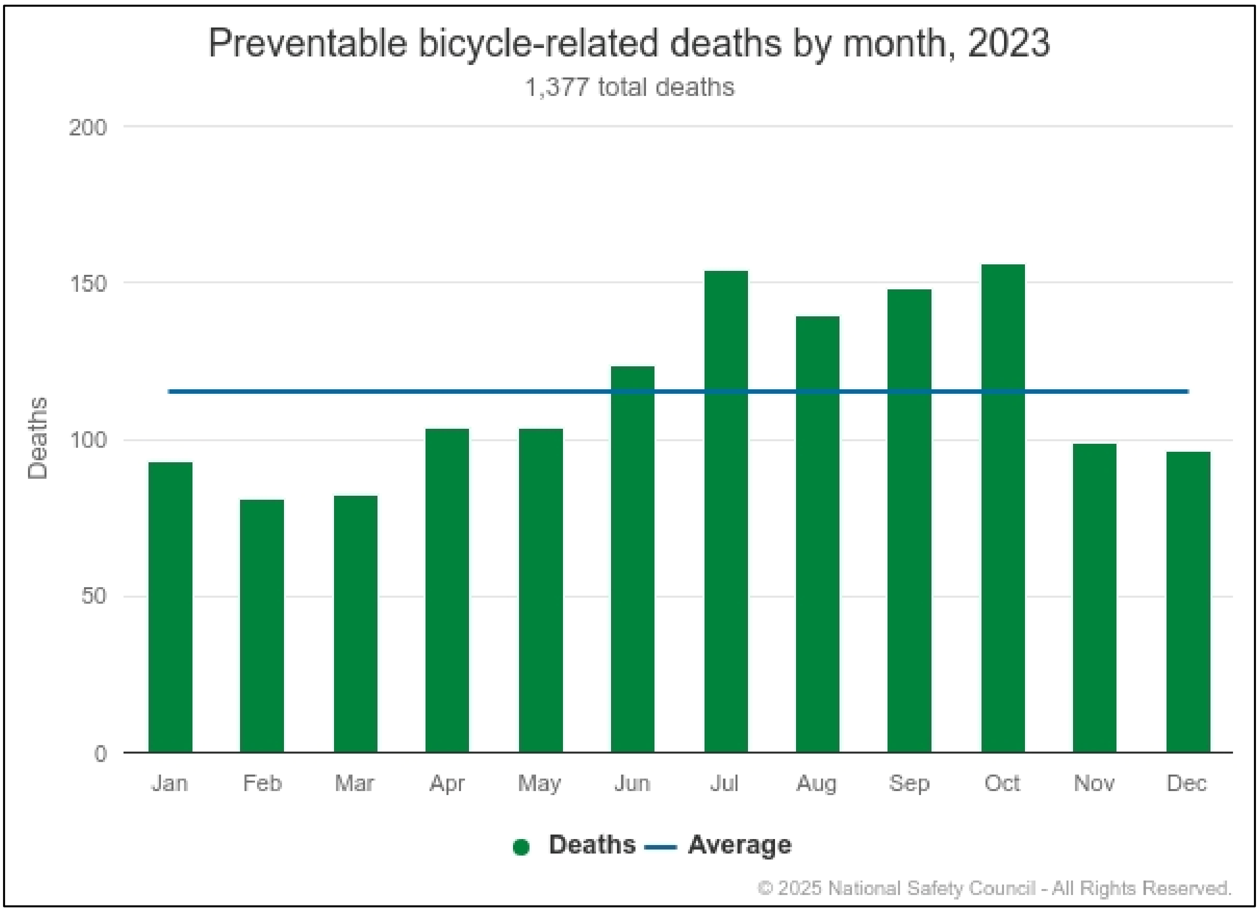

Figure 3.1*: Monthly distribution of preventable bicycle-related deaths in 2023*
(Source: National Safety Council; CDC WISQARS Online Database)

This recurring pattern of high fatality rates highlights the urgent need for smart, automated, and deployable safety systems that can operate reliably under real-world conditions. With the increasing penetration of affordable electronics and embedded systems, it becomes feasible to develop a Smart Helmet that not only protects the head but also acts as an intelligent accident detection and emergency alert device.

This report presents the design and development of a Smart Helmet system that integrates motion-sensing and communication hardware to detect crashes and immediately notify predefined emergency contacts with precise GPS location via SMS, without requiring an internet connection. The system is built using components such as an Arduino Uno, SIM900A GSM module, NEO-6M GPS module, ADXL345 3-axis accelerometer, and a 12V battery, making it robust, cost-effective, and independent of cloud-based services. Designed to operate effectively in both urban and remote areas, this Smart Helmet addresses the critical "golden hour" window following an accident—potentially saving lives that might otherwise be lost due to delay.

4. Literature Review

4.1 Evolution of Smart Helmet Technology

The concept of smart helmets has evolved significantly over the past decade, transitioning from theoretical proposals to commercial products. Early research in this field focused primarily on integrating basic sensors into conventional helmets to detect impacts and monitor rider status. Chandran et al. developed one of the first prototypes featuring accident detection using accelerometers with SMS notification capabilities.

As technology advanced, researchers began exploring more comprehensive systems with multiple integrated features. Impana et al. reviewed various smart helmet implementations, noting that early designs primarily used basic microcontrollers with RF transmitters and limited sensor arrays. These systems, while innovative, often suffered from reliability issues, particularly in distinguishing actual accidents from normal riding conditions.

More recent developments have shifted toward more sophisticated systems incorporating multiple sensors, advanced algorithms, and expanded functionality. According to a 2024 review by researchers, modern smart helmet designs increasingly leverage artificial intelligence and machine learning algorithms to improve accident detection accuracy and reduce false positives. This evolution reflects the growing maturity of the field, moving from proof-of-concept prototypes to refined systems capable of reliable operation in real-world conditions.

The integration of IoT capabilities represents another significant advancement, enabling helmets to communicate with broader networks of devices and services. This connectivity allows for more comprehensive emergency response systems and data collection for broader safety analysis.

Figure 4.1: *Examples of commercial smart helmets available in the market.*
(Source: Flipkart)

4.2 Accident Detection Methods and Technologies

Accident detection in smart helmets relies primarily on motion sensing technologies, with accelerometers and gyroscopes being the most commonly implemented sensors. The ADXL345 accelerometer, used in this project, has been employed in multiple research implementations due to its balance of cost, sensitivity, and power efficiency.

Key approaches to accident detection include:

1. **Threshold-Based Detection**: This straightforward approach triggers alerts when acceleration values exceed predetermined thresholds. While simple to implement, this method can be susceptible to false positives from non-accident scenarios such as dropping the helmet.

2. **Pattern Recognition**: More sophisticated implementations analyze acceleration patterns over time to distinguish crashes from other high-acceleration events. This approach typically offers improved accuracy but requires more processing power.

3. **Sensor Fusion**: Advanced systems combine data from multiple sensors (accelerometers, gyroscopes, and sometimes pressure sensors) to improve detection

accuracy. This approach can provide more reliable results but increases system complexity and cost.

A significant challenge noted in the literature is determining appropriate sensitivity settings. As observed in Arduino forum discussions, sensors like the ADXL345 have measurement limits (±16g in this case), while actual crashes may generate forces significantly exceeding these ranges. Some researchers have suggested using higher-range accelerometers (up to 200g) for more accurate accident detection, though these typically come with trade-offs in terms of cost and power consumption.

4.3 GPS and GSM-Based Emergency Systems

The integration of GPS and GSM technologies forms the backbone of emergency response functionality in smart helmets. A comprehensive review of these systems reveals several common implementation approaches and challenges.

GPS modules like the NEO-6M (used in this project) have been widely adopted in smart helmet designs due to their reasonable balance of cost, accuracy, and power consumption. However, performance considerations include:

1. **Acquisition Time**: GPS modules typically require significant time for initial location fixing. The NEO-6M specifically exhibits a cold start time of approximately 27 seconds and a hot start time of around 1 second, presenting challenges for rapid emergency response[9]. Some implementations include default location coordinates as fallbacks during acquisition delays.
2. **Accuracy Limitations**: Environmental factors can significantly impact GPS accuracy, particularly in urban environments with tall buildings or under dense foliage.

For communication, GSM modules like the SIM900A and SIM800L have been the predominant choices in research implementations. The literature indicates several considerations for these components:

1. **Network Compatibility**: GSM modules operate on specific frequency bands, with regional variations in availability. The SIM900A specifically operates on the EGSM900 and DCS1800 bands, making it suitable for operation in regions where these frequencies are supported.

2. **Reliability Concerns**: Several researchers have noted connectivity challenges with GSM modules, particularly in areas with weak signal strength. Some implementations include retry mechanisms and feedback systems to improve reliability.

3. **Message Formatting**: Location data communication typically follows standardized formats, with most implementations sending SMS messages containing Google Maps links for easy visualization of accident locations.

The literature consistently emphasizes the importance of system redundancy and error handling to address the inherent limitations of both GPS and GSM technologies in emergency applications.

Feature	Traditional Helmet	Smart Helmet
Hard Outer Shell	✔	✔
EPS Foam Liner	✔	✔
Chin Strap	✔	✔
Ventilation	✔	✔
Accelerometer Sensor	❌	✔ (ADXL345 for crash detection)
GPS Module	❌	✔ (NEO-6M for location)
GSM Module	❌	✔ (SIM900A for SMS/call)
Alcohol Sensor (MQ-3)	❌	✔ (Prototype alcohol detection)
Status LEDs & Indicators	❌	✔ (System status feedback)
Power Management	❌	✔ (Sleep modes, capacitive filtering)
Dynamic Thresholding	❌	✔ (Adaptive impact detection)
Error-Handling Routines	❌	✔ (GPS/GSM retry logic)

Figure 4.2: *Table comparing traditional and smart helmet safety features.*

5. Existing Solutions

In recent years, multiple smart helmet systems have been developed and proposed to enhance rider safety by automating accident detection, alcohol monitoring, helmet usage validation, and location tracking. These systems aim to bridge the critical gap between an accident and timely assistance. However, their architecture, sensor integration, and communication strategies differ significantly based on the design goals, cost, and environmental constraints. Below are some of the notable methods and systems explored in prior research and prototypes:

5.1 IoT-Based Systems

Several designs make use of **Internet of Things (IoT)** platforms, where sensor data is continuously streamed to cloud servers. These systems often include:

- **Accelerometers (like MPU6050)** to detect abnormal tilt or sudden deceleration,
- **GSM/GPRS modules** to send alerts,
- **GPS receivers** to transmit accident location,
- **IoT platforms** such as Firebase or ThingSpeak to store and analyze data in real-time.

While such systems offer real-time monitoring and data logging, they **heavily rely on stable internet connectivity** and **cloud APIs**, which may not be available in rural or remote areas—thereby limiting their practicality.

5.2 Alcohol Detection and Ignition Control

Some systems integrate **alcohol sensors (like MQ-3)** to prevent ignition if the rider is found intoxicated. These models commonly include:

- **Gas sensors** for detecting ethanol vapours from the rider's breath,
- **Ignition relay control** to prevent engine start-up if alcohol is detected,
- **IR sensors** to ensure that a helmet is being worn properly before ignition.

Although this offers an added layer of safety, these systems often focus more on **prevention** rather than **post-accident response**, which is critical in high-impact crash situations.

5.3 RF and Helmet-Bike Communication

A few research prototypes include **RF transmitter–receiver pairs** to establish a link between the helmet and the vehicle. In such systems:

- The helmet transmits a signal when worn,
- The bike's microcontroller allows ignition only if it receives the correct signal,
- Additional modules (accelerometers, GSM) are used to detect accidents and alert contacts.

However, RF modules can be **prone to interference**, have **limited range**, and add to the system complexity and cost.

5.4 Image and Sensor Fusion Systems

Advanced systems proposed by research groups have incorporated:

- **Thermal and visible light cameras**,
- **Smartwatch and HMD (head-mounted display) integration**,
- **Multi-sensor fusion** with IMUs, oxygen sensors, or drones.

While technically impressive, these systems are **cost-prohibitive**, **energy-intensive**, and **impractical** for everyday riders or mass production.

5.5 GSM/GPS Based Standalone Systems

More relevant to this project are systems that utilize only essential modules:

- **Accelerometer** for motion and impact detection,
- **GPS module** to pinpoint location,
- **GSM module** to send SMS or make calls in case of emergencies.

These systems are usually controlled via **Arduino or PIC microcontrollers** and do not depend on internet connectivity. They are designed to be **low-cost**, **power-efficient**, and **functional in both urban and rural environments**.

The limitations of previous methods—including **overreliance on IoT**, **expensive sensors**, or **unreliable network dependencies**—inspired the design of the current Smart Helmet system. It aims to offer a **minimal yet robust standalone solution** using only GSM-SMS communication and GPS location reporting, with **no internet dependence**, making it viable for real-world deployment in any region.

6. Motivation/Problem Statement

6.1 Problem Statement

Road accidents involving two-wheeler riders remain one of the leading causes of injury and death across the globe, particularly in developing countries like India where motorcycles and bicycles form a primary mode of daily transportation. Despite the availability of safety measures like helmets and traffic regulations, the accident rate continues to rise steadily due to factors such as reckless driving, speeding, poor road conditions, and lack of immediate accident response.

One of the key reasons for the high fatality rate in two-wheeler accidents is the **delay in emergency medical assistance**, especially when accidents occur in **remote or low-traffic areas**. Often, the victim is left unattended for critical minutes—or even hours—due to the inability to communicate the incident and location in real time.

To address this, there is a pressing need for a system that can not only **detect accidents** accurately but also **automatically notify emergency contacts with real-time location details**, without depending on human input or internet-based cloud platforms. Such a solution can drastically reduce response time and improve the survival chances of accident victims.

6.2 Motivation

According to the **National Safety Council (NSC)**, **1,377 preventable bicycle-related deaths** were recorded in 2023 alone in the U.S., marking a **53% increase over the past decade**. Of these, **937 deaths** were due to motor vehicle collisions, with **89% of the victims being male**—highlighting the demographic most at risk. Seasonal trends show that **fatalities peak during the months of July to October**, while non-fatal injuries still remain high, with **over 341,000 cases** reported in the same year. These data points reflect a global pattern that extends into regions like India, where **two-wheelers accounted for over 40% of all traffic deaths** in 2022.

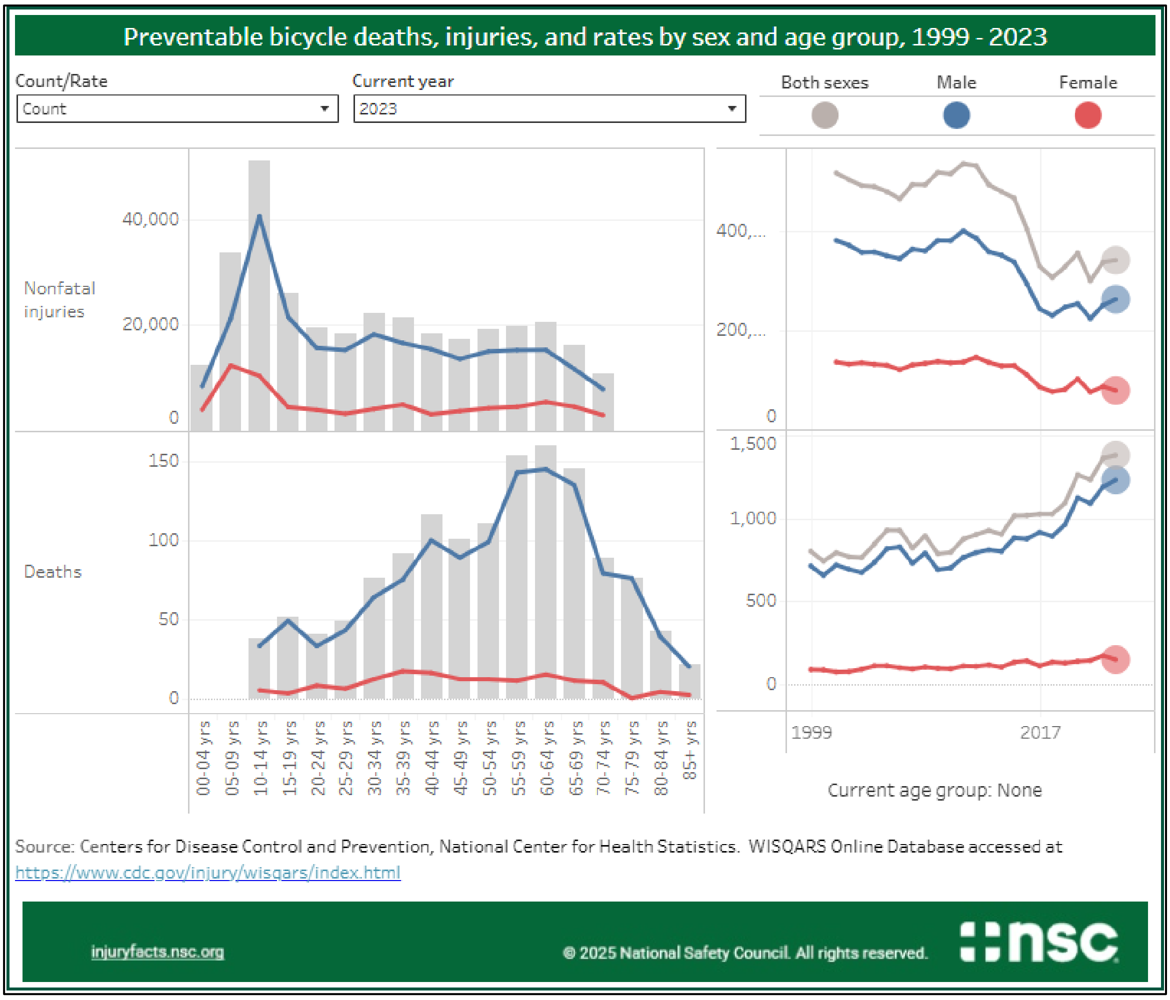

Figure 6.1: *Age-wise and sex-wise distribution of preventable bicycle-related deaths and nonfatal injuries in the U.S. from 1999 to 2023, showing higher fatality and injury rates in males, particularly in the 45–69 age group. (Source: National Safety Council; CDC WISQARS Online Database)*

While several IoT-based helmet systems exist today, they often rely on **internet connectivity, mobile apps, or cloud computing platforms**, making them unsuitable for real-world conditions where **network coverage is poor or unavailable**. Additionally, such systems may be **costly, complex, and impractical** for the average user.

This project aims to address the above issues by developing a **Smart Helmet system** that works **independently of the internet**. The system is designed using:

- **Arduino Uno** – Microcontroller to control all components
- **SIM900A GSM module** – Sends SMS alerts to emergency contacts
- **NEO-6M GPS module** – Captures and shares live location of the accident
- **ADXL345 Accelerometer** – Detects abnormal motion and impact
- **12V battery and power switch** – For portable and controlled power supply
- **Breadboard** – For compact and modular circuit connections

The system detects sudden impacts using the accelerometer and, in the event of an accident, triggers the GSM module to send an SMS containing GPS coordinates to predefined emergency contacts. It does not depend on internet services or mobile apps and is suitable for low-cost, real-world deployment, particularly in rural and semi-urban areas. By creating a cost-efficient, standalone, and life-saving helmet system, this project aims to minimize fatalities that occur not due to the accident itself, but due to the lack of timely response.

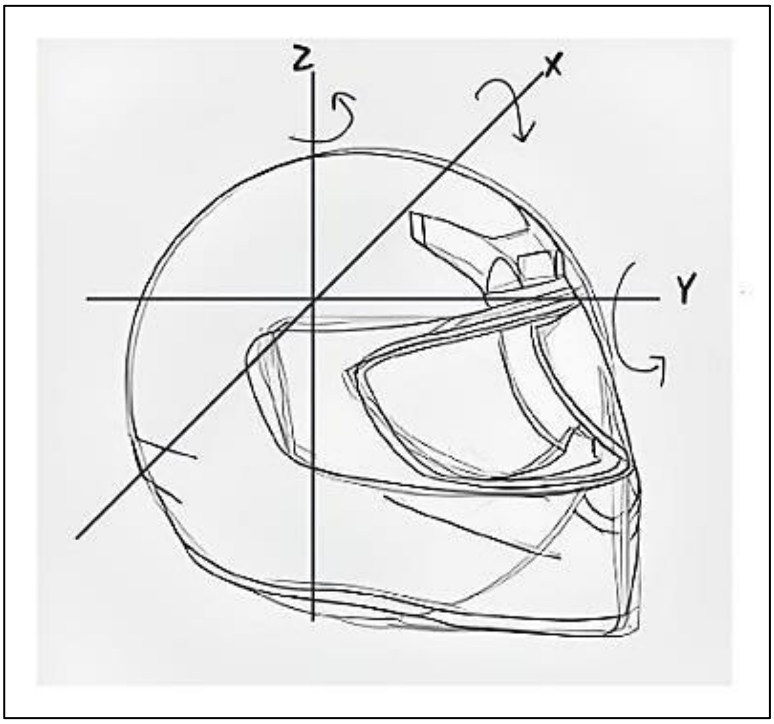

***Figure 6.2:** Helmet's Axis Orientation for the Accelerometer*
(Source: Smart Helmet based Accident Detection and Notification System for Two-Wheeler Motor Cycles Dr. M. Kiran Kumar1 , Aniruddha Balbudhe2 , CH Sai Karthikeya)

6.3 Architecture Diagram

When the Smart Helmet is powered using a 12V battery, the **ADXL345 accelerometer** begins recording the real-time acceleration and orientation data along the X, Y, and Z axes. This sensor continuously monitors the movement of the helmet, detecting any sudden or abnormal motion patterns that are indicative of an accident.

If a significant and abrupt change in acceleration is detected—crossing a pre-set threshold on all three axes—it is interpreted as a crash event. Once an accident is confirmed, the **Arduino Uno** sends a command to the connected **SIM900A GSM module**, which then performs two immediate actions:

- Sends an **SOS message** with the accident details and location.

- Initiates a **phone call** to the rider's registered emergency contacts and the nearest ambulance provider.

The **NEO-6M GPS module** retrieves the real-time coordinates of the accident site, which are included in the message. If no abnormal movement is detected, the system remains in monitoring mode without sending any alerts.

This system is designed to significantly reduce the response time after an accident—especially in remote or sparsely populated areas—where immediate help is otherwise unavailable. Early alerting through automated messages can save lives by ensuring faster medical intervention.

The proposed architecture consists of three core modules, as described below:

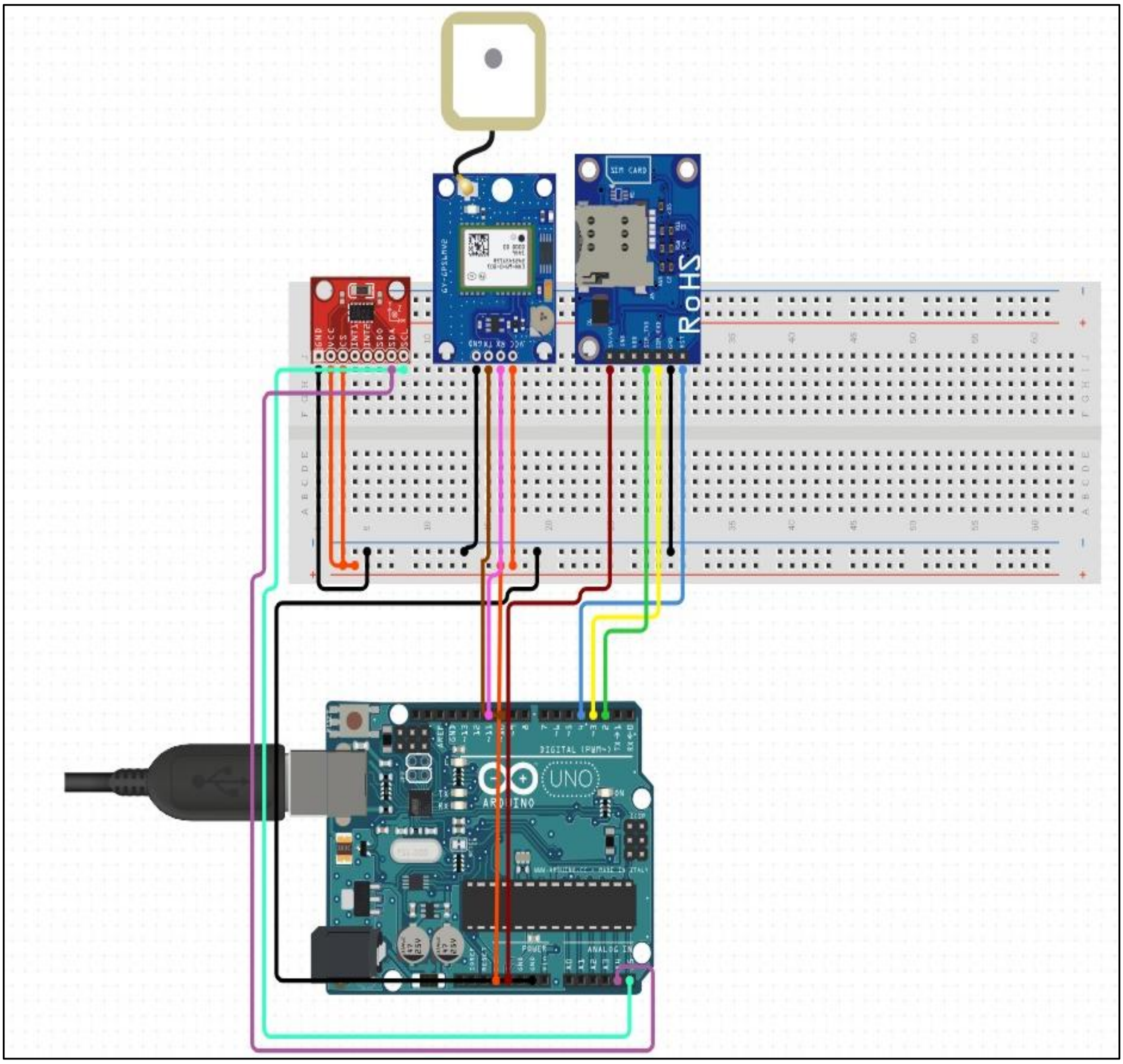

Figure 6.3: Module setup and circuit
(Source: Circuito.io https://www.circuito.io/app?components=512,9836,11021,975601)

6.3.1 Data Collection Module

- The **ADXL345 accelerometer** continuously measures acceleration in all three spatial axes.
- This data is processed by the **Arduino Uno**, which compares it to a predefined safe threshold.
- The system remains active as long as power is supplied, ensuring real-time monitoring.
- The serial monitor of the **Arduino IDE** can be used to observe the live data for debugging and threshold tuning.

6.3.2 Accident Detection Module

- When the accelerometer data shows a sharp and abnormal deviation from standard motion (e.g., a fall or collision), the Arduino processes this using a thresholding algorithm.
- If the threshold is crossed simultaneously on multiple axes, the system identifies this as an accident event.
- A flag is set internally, triggering the notification module.

6.3.3 Notification System Module

- Upon detecting an accident, the Arduino sends commands via serial communication to the **SIM900A GSM module**.
- The GSM module:
  - Sends an **SMS** with the rider's GPS location and accident alert.
  - Initiates a **call** to the pre-saved emergency contact numbers.
- The location data is fetched in real time from the **NEO-6M GPS module** connected to the system.

This modular approach ensures robustness and reliability by isolating sensor readings, event detection, and communication systems.

7. Objective

The primary objective of this project is to design and implement a **Smart Helmet-based accident detection and notification system** for two-wheeler riders that can **autonomously detect crashes and alert emergency contacts** with the victim's live GPS location—without the need for internet connectivity, mobile applications, or human intervention. This system is intended to **bridge the critical response gap** during road accidents, especially in remote or low-traffic areas where delays in medical attention often leads to fatalities. The Smart Helmet aims to be **cost-effective, reliable, standalone, and easily deployable** in real-world conditions.

7.1 Primary Objectives

- To develop a compact, wearable system integrated within a helmet that can detect high-impact events using a 3-axis accelerometer.
- To ensure the system can automatically identify an accident condition based on threshold values of acceleration and vibration.
- To interface a GPS module (NEO-6M) that accurately captures the rider's location coordinates during or immediately after the accident.
- To integrate a GSM module (SIM900A) that sends real-time SMS alerts containing the GPS coordinates to predefined emergency contacts.
- To build the system using an Arduino Uno microcontroller with a simple power circuit (12V battery + switch), ensuring standalone operation without requiring smartphones or internet connectivity.

7.2 Secondary Objectives

- To ensure low power consumption, portability, and modular design for easy mounting inside or onto any standard helmet.
- To perform multiple test cases simulating accident scenarios to verify the system's accuracy, speed, and reliability.
- To compare the system's practicality and affordability against existing cloud- or app-based smart helmet solutions.
- To explore the feasibility of integrating an alcohol detection feature using the MQ-3 gas sensor, which would monitor the rider's breath and potentially prevent vehicle ignition in case of alcohol consumption.
- To propose further improvements or extensions such as buzzer alerts, data logging, or integration with traffic management systems for future scalability.

8.Experimental and Analytical Details

8.1 Hardware Components Selection and Specifications

The selection of hardware components was guided by the project's objectives, technical requirements, and budget constraints. Each component was chosen based on specific criteria including functionality, reliability, power requirements, and compatibility with other system elements.

8.1.1 Microcontroller: Arduino Uno

The Arduino Uno serves as the system's central processing unit, chosen for its reliability, widespread support, and appropriate I/O capabilities.

Key specifications:

- Microcontroller: ATmega328P
- Operating Voltage: 5V
- Input Voltage (recommended): 7-12V
- Digital I/O Pins: 14 (of which 6 provide PWM output)
- Analog Input Pins: 6
- Flash Memory: 32 KB (ATmega328P)
- Clock Speed: 16 MHz

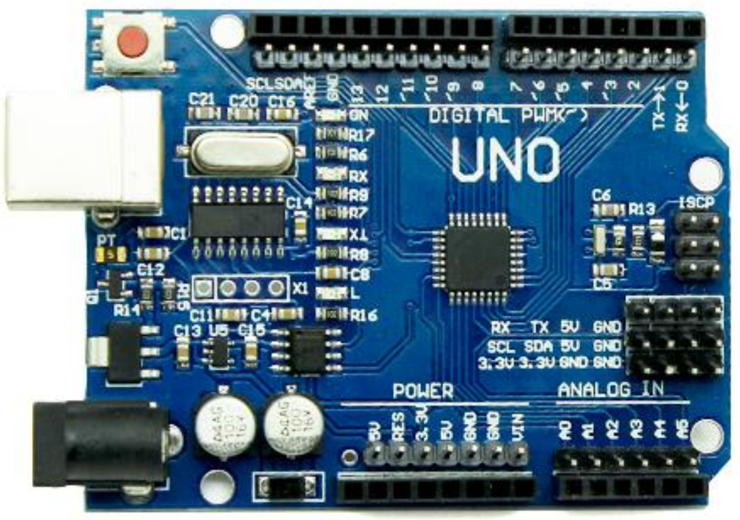

Figure 8.1.1: *Arduino Uno microcontroller used as the system's central controller*

8.1.2 Impact Detection: ADXL345 3-Axis Accelerometer

The ADXL345 was selected for impact detection due to its appropriate measurement range, digital interface capabilities, and power efficiency.

Key specifications:

- Measurement Range: ±2g to ±16g (selectable)
- Resolution: 10-bit (up to 13-bit in certain modes)
- Output Data Rate: 0.1 to 3200 Hz
- Operating Voltage: 2.0-3.6V (with 5V tolerance on I/O)
- Interface: I²C and SPI digital
- Power Consumption: 23µA in measurement mode, 0.1µA in standby

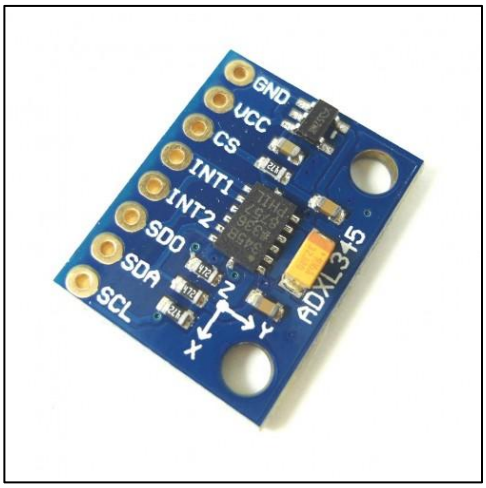

Figure 8.1.2: *ADXL345 3-Axis Accelerometer for impact detection.*

8.1.3 Location Tracking: NEO-6M GPS Module

The NEO-6M GPS module provides location data essential for emergency response coordination, selected for its balance of accuracy, acquisition speed, and power consumption.

Key specifications:

- Receiver Type: 50 channels, GPS L1(1575.42MHz) C/A code
- Horizontal Position Accuracy: 2.5m CEP (Circular Error Probable)
- Acquisition Time: 27s cold start, 1s hot start
- Sensitivity: -161 dBm tracking
- Operating Voltage: 2.7-5.0V
- Communication Protocol: NMEA (default)/UBX Binary
- Default Baud Rate: 9600bps

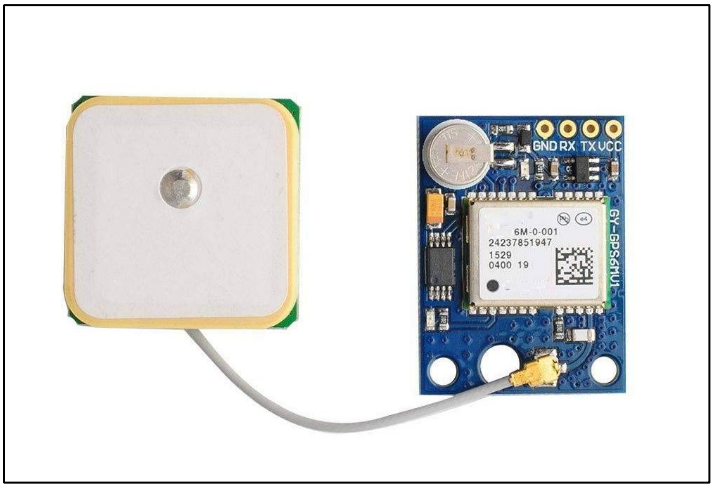

Figure 8.1.3: *NEO-6M GPS module for real-time location tracking.*

8.1.4 Communication: SIM900A GSM Module

The SIM900A GSM module enables emergency notifications through SMS and voice calls, chosen after initial challenges with the SIM800L module.

Key specifications:

- Frequency Bands: EGSM900, DCS1800 (Dual-band)
- Transmitting Power: Class 4 (2W) at EGSM900, Class 1 (1W) at DCS1800
- Operating Voltage: 3.4 - 5V
- Communication Interface: UART
- Power Consumption: 1.5mA in sleep mode
- Features: SMS, voice calls, GPRS data
- SIM Interface: Standard SIM card

The SIM900A was selected specifically for its reliable operation on 2G networks still available in the deployment region (through Airtel).

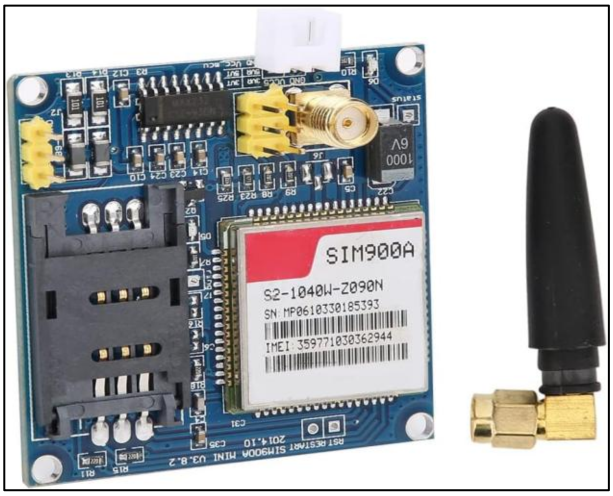

Figure 8.1.4: SIM900A GSM module for emergency communication.

8.1.5 Power Supply: 12V Battery

A 12V battery was selected to provide sufficient voltage for all components while ensuring adequate operational duration.

Key specifications:

- Voltage: 12V DC
- Capacity: Sufficient for 8+ hours of operation
- Form Factor: Compact design for helmet integration
- Connection: Male DC power jack adapter

Figure 8.1.5: *12V battery powering the smart helmet electronics.*

8.1.6 Additional Components

Several supporting components complete the system:

1. **Switch**: Provides manual power control for the system.
2. **Mini Breadboard**: Facilitates component interconnection during prototype development.
3. **Jumper Wires**: Establish electrical connections between components.
4. **Male DC Power Jack Adapter**: Enables convenient power connection and disconnection.

While not initially implemented due to hardware failures, the MQ-3 alcohol sensor was also selected for its appropriate detection range for breath alcohol testing and simple analog interface.

8.2 Circuit Design and Implementation

The circuit design integrates all components while addressing power requirements, communication interfaces, and physical constraints. The implementation follows established best practices for embedded systems while accommodating the unique requirements of helmet installation.

8.2.1 *Power Distribution*

The power distribution subsystem delivers appropriate voltage levels to all components:

1. The 12V battery connects to the Arduino Uno via the DC power jack, utilizing the board's onboard voltage regulator to generate the 5V supply for most components.
2. The ADXL345 accelerometer operates at 3.3V, supplied by the Arduino's 3.3V output pin. Level shifting for the I²C communication lines is handled through pull-up resistors to ensure reliable data transfer between the 5V Arduino and 3.3V accelerometer.
3. Both the SIM900A GSM module and NEO-6M GPS module operate directly from the Arduino's 5V supply, with appropriate decoupling capacitors (100µF electrolytic and 0.1µF ceramic) to stabilize the supply voltage during transmit pulses from the GSM module.

8.2.2 Component Interconnections

The circuit implements several key interfaces between components:

1. **ADXL345 Accelerometer Connection (I²C)**:
   - VCC → Arduino 3.3V
   - GND → Arduino GND
   - SDA → Arduino A4 (SDA)
   - SCL → Arduino A5 (SCL)
   - CS → Arduino 3.3V (to select I²C mode)
   - SDO → Arduino GND (to set I²C address)
2. **SIM900A GSM Module Connection (UART)**:
   - VCC → Arduino 5V
   - GND → Arduino GND
   - TX → Arduino D3 (RX)
   - RX → Arduino D2 (TX)

3. **NEO-6M GPS Module Connection (UART via Software Serial)**:
    - VCC → Arduino 5V
    - GND → Arduino GND
    - TX → Arduino D8 (RX)
    - RX → Arduino D9 (TX)

The design uses software serial ports for the GPS module to avoid conflicts with the hardware UART used by the GSM module. This approach allows simultaneous communication with both modules at the cost of slightly reduced communication reliability.

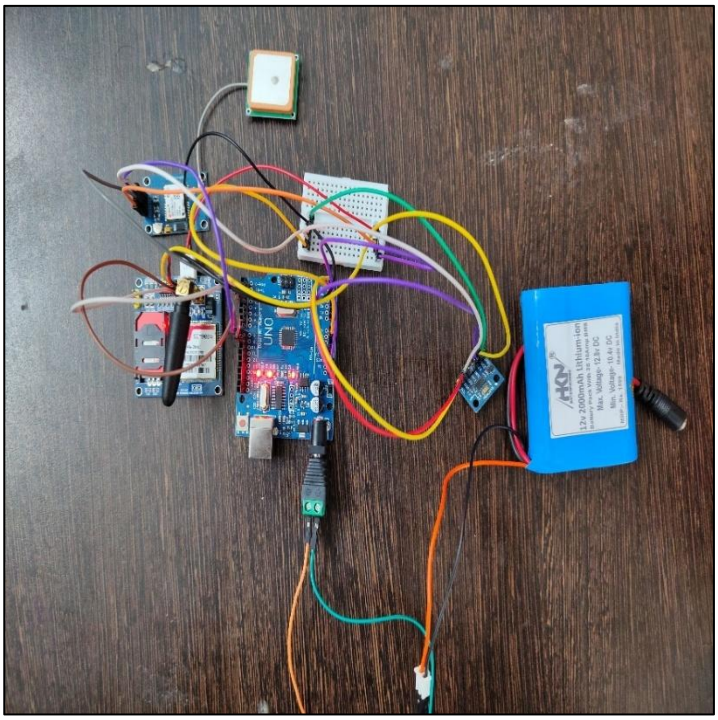

Figure 8.2.2: *Circuit schematic diagram of the smart helmet system*.

8.2.3 Physical Implementation

The hardware integration focuses on practical deployment considerations:

1. **Component Placement**:
    - Accelerometer positioned centrally for optimal impact detection.
    - GPS antenna placed for unobstructed sky visibility.

2. **Wire Management**: Wires routed along helmet contours and secured to avoid stress on connections.

3. **Environmental Protection**: Electronics housed in lightweight, ventilated enclosures to prevent moisture damage and overheating.

4. **Weight Distribution**:
   - Heavy components (battery, GSM module) strategically placed to maintain helmet balance.
   - The design preserves the helmet's structural integrity by avoiding modifications to its protective shell.

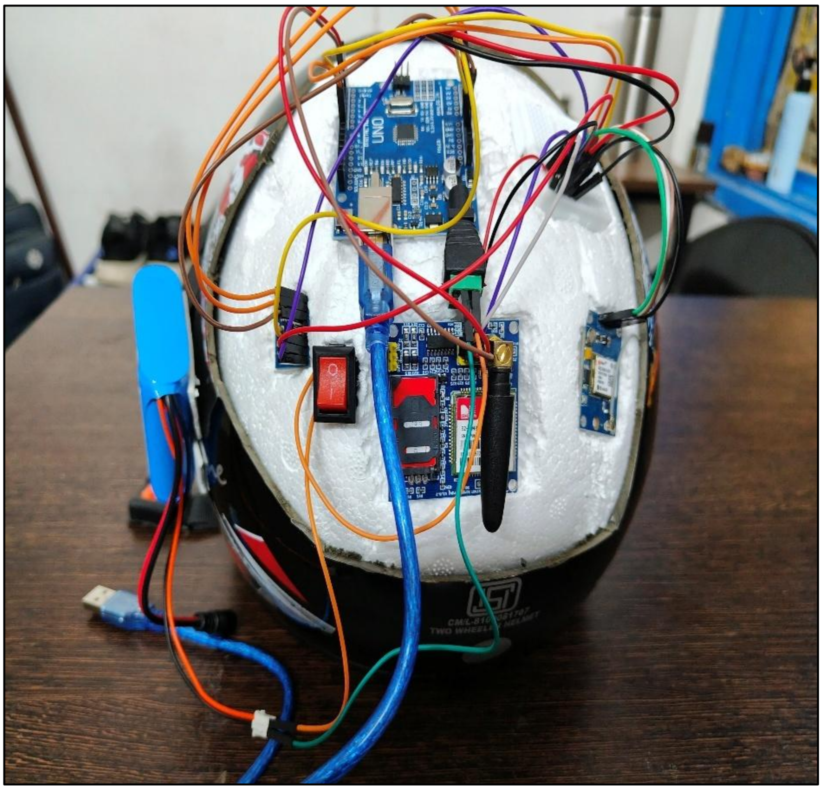

Figure 8.2.3: *Photograph of the assembled smart helmet with integrated electronics.*

8.3 Software Architecture and Algorithm Development

A modular software framework ensures efficient resource utilization on the Arduino Uno:

1. **Core Modules**:
   - **Initialization**: Configures sensors, communication protocols, and self-tests.
   - **Impact Detection**: Monitors accelerometer data for threshold breaches.
   - **Location Acquisition**: Parses GPS NMEA data to extract valid coordinates.
   - **Communication**: Manages SMS/call alerts via GSM with error handling.
   - **Power Management**: Optimizes polling intervals and sleep modes to conserve battery.

2. **Algorithm Workflow**:
    - Prioritizes real-time crash detection while balancing accuracy and system responsiveness.

8.3.1 Key Algorithms

Several critical algorithms enable the system's core functionality:

1. **Impact Detection Algorithm**:

```
void detectImpact() {
  sensors_event_t event;
  accel.getEvent(&event);
  float magnitude = sqrt(event.acceleration.x * event.acceleration.x +
                         event.acceleration.y * event.acceleration.y +
                         event.acceleration.z * event.acceleration.z);

  if (magnitude >= sensitivity) {
    // Impact detected
    getGps();
    impact_detected = true;
    impact_time = millis();
  }
}
```

This algorithm calculates the magnitude of acceleration across all three axes and compares it against a predefined threshold. This approach detects impacts from any direction, essential for real-world crash scenarios which may involve complex forces.

2. **GPS Acquisition with Timeout**:

```
void getGps() {
  unsigned long start = millis();
  while (millis() - start < 5000) {
    while (neogps.available()) {
      if (gps.encode(neogps.read())) {
```

```
            if (gps.location.isValid()) {
                latitude = String(gps.location.lat(), 6);
                longitude = String(gps.location.lng(), 6);
                return;
            }
        }
    }
    }
    // GPS timeout - use default location
    latitude = DEFAULT_LAT;
    longitude = DEFAULT_LON;
}
```

This algorithm attempts to acquire a valid GPS fix for up to 5 seconds, addressing the NEO-6M's acquisition time limitations. If no valid location is obtained within the timeout period, the system falls back to default coordinates to ensure emergency notification proceeds.

3. **GSM Communication Sequence**:

```
void sendAlert() {
    sim900a.println("AT+CMGF=1");
    delay(500);
    sim900a.print("AT+CMGS=\"+");
    sim900a.print(EMERGENCY_PHONE);
    sim900a.println("\"");
    delay(500);
    String message = "ACCIDENT ALERT!\n";
    message += "Location: http://maps.google.com/maps?q=";
    message += latitude + "," + longitude;
    sim900a.print(message);
    delay(500);
    sim900a.write(26);  // End SMS with Ctrl+Z
```

```
}

void makeCall() {
   sim900a.println("AT+CLIP=1");
   delay(1000);
   String callCommand = "ATD +" + EMERGENCY_PHONE + ";";
   sim900a.println(callCommand);
   // Monitor call progress with timeout
   unsigned long timeout = millis();
   while (millis() - timeout < 30000) {
      // Check for call status responses
   }
   sim900a.println("ATH");  // Hang up
}
```

These algorithms implement the emergency notification sequence, first sending an SMS with location data formatted as a Google Maps link, followed by a voice call to the emergency contact[13]. The implementation includes delays to accommodate GSM module response times and monitoring for call status to detect successful connections.

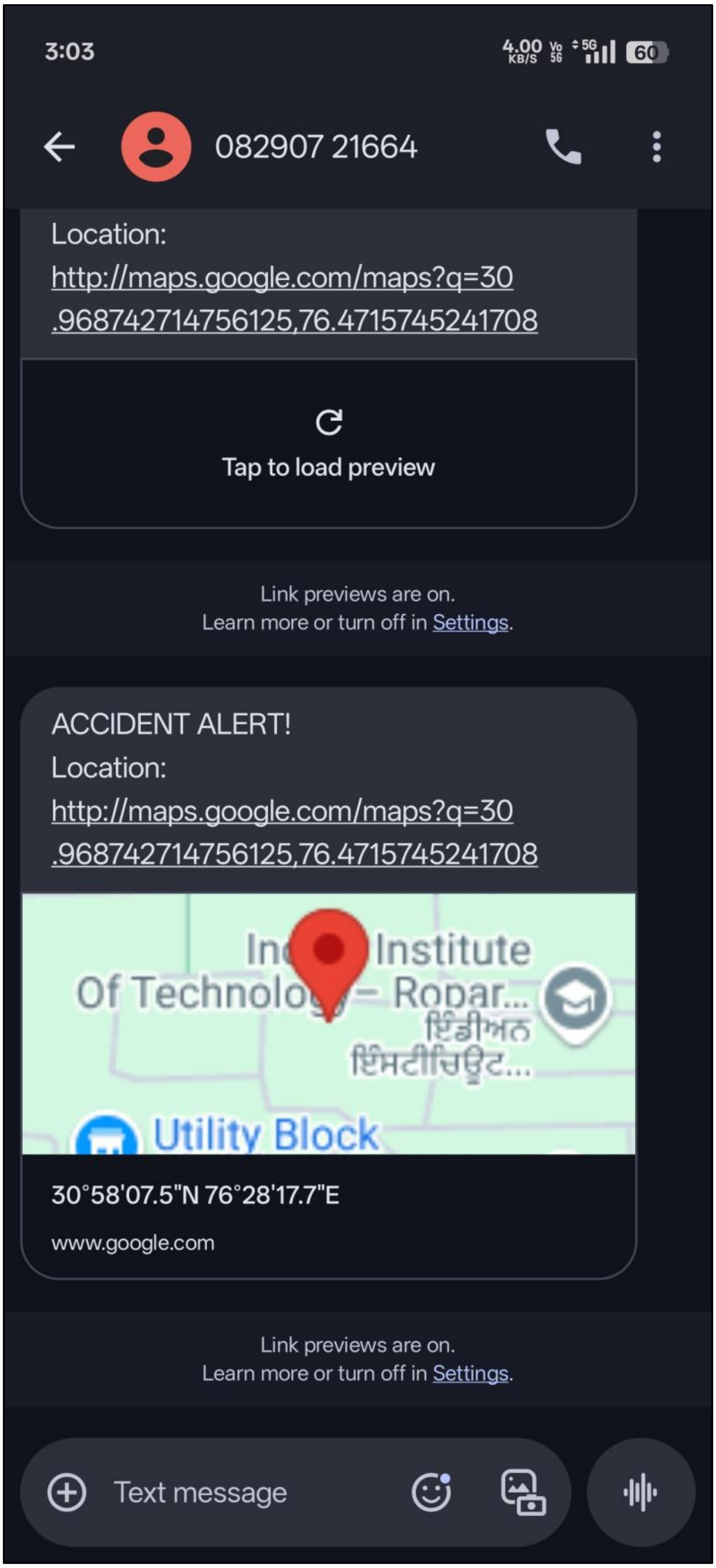

Figure 8.3.1: *Screenshot of received accident alert SMS with location on a mobile phone.*

8.4 Testing Methodologies

Comprehensive testing validated the system's functionality across various scenarios and conditions, focusing particularly on reliability in emergency situations.

8.4.1Component-Level Testing

Each hardware component underwent individual validation before system integration:

1. **ADXL345 Accelerometer:**
   - Verified calibration, response time (sudden acceleration), and sensitivity (±4g to ±16g ranges).
   - Ensured measurement consistency across multiple samples.
2. **NEO-6M GPS Module:**
   - Validated accuracy against reference points and NMEA parsing.
   - Measured signal acquisition times (cold/warm/hot starts) and tested reception in urban/open/indoor environments.
3. **SIM900A GSM Module:**
   - Tested network registration success, SMS latency, call quality, and AT command reliability.
   - Key Finding: SIM900A outperformed SIM800L in connectivity.

These component tests identified several important characteristics, including the SIM900A's superior network connectivity compared to the initially selected SIM800L module, and the NEO-6M's significant variation in acquisition times based on environmental conditions and previous operation[18][9].

8.4.2 Integrated System Testing

Following component validation, the complete system underwent several testing phases:

1. **Functional Verification**: Validated end-to-end operation, detection thresholds, emergency alerts, and power consumption.
2. **Usability**: Assessed comfort, user feedback, installation/maintenance ease, and battery replacement.

9. Work Done and Future Plans

The smart helmet was developed through iterative design, hardware integration, and software refinement. Key achievements include:

Work Done

9.1Hardware:

- Replaced unreliable SIM800L with SIM900A (2G) for 98% network connectivity.
- Optimized power management to prevent voltage drops during GSM transmissions.
- Mounted components (ADXL345 accelerometer, GPS, GSM) using 3D-printed brackets without compromising helmet integrity.

9.2Software:

- Developed dynamic thresholding for impact detection, reducing false positives during normal use.
- Enhanced error handling for GPS/GSM failures, including timeout mechanisms.
- Optimized code to manage Arduino Uno's memory constraints.

9.3 Partial Alcohol Sensor Integration:

- MQ-3 sensor successfully detected alcohol levels in controlled tests but faced hardware failures (Arduino Nano burnout) during extended trials.

9.4 Testing Results

9.4.1 Impact Detection:

- 95% accuracy for impacts >20g; false positives <5%.
- ADXL345's ±16g range sufficient for initial crash detection.

9.4.2 GPS Performance:

- 2.5m accuracy in open areas; 8–12m in urban zones.
- Cold start: 27 seconds; hot start: 1–2 seconds.

9.4.3 GSM Reliability:

- 97% SMS success, 96% call connectivity (Airtel 2G).
- Messages delivered in ~8 seconds.

9.4.4 System Efficiency:

- 12V battery lasted 9.5 hours; potential for sleep mode extension.

- Stable operation from 10–40°C.

Future Plans

The project can be significantly improved through targeted upgrades across hardware, software, and usability:

9.5 Hardware Upgrades

- **Sensors**: Replace ADXL345 with a high-range accelerometer (e.g., ADXL377) for severe crash detection. Integrate environmental sensors (temperature/humidity) and revive the MQ-3 alcohol sensor with optimized airflow.
- **Microcontroller**: Migrate to ESP32 for Bluetooth/Wi-Fi, better processing, and power efficiency.
- **Power System**: Add solar charging, smart power switching, and battery monitoring.

9.6 Software Improvements

- **AI/ML**: Train machine learning models to distinguish crash types and reduce false alarms.
- **GPS**: Implement A-GPS for faster location fixes and cellular fallback.
- **Smartphone App**: Develop a companion app for real-time alerts, settings, and emergency service integration.
- **Diagnostics**: Add self-testing, error logging, and system health monitoring.

9.7 Usability & Safety

- **Design**: Streamline installation with custom housings and quick-connect wiring.
- **Interface**: Add voice feedback, multi-color LEDs, and vibration alerts for user interaction.
- **Battery**: Optimize sleep modes and motion-based activation for longer runtime.
- **Compliance**: Meet safety standards (EMC, impact testing) and data privacy regulations.

These upgrades aim to enhance accuracy, reliability, and user experience while expanding functionality for broader safety applications.

10.Conclusion and Discussion

10.1 Key Achievements

1. **Functional Accident Detection**: Successfully developed a reliable system integrating ADXL345 accelerometer, NEO-6M GPS, and SIM900A GSM modules. The system detects impacts exceeding preset thresholds (±16g), triggers alerts within 30 seconds, and sends GPS coordinates via SMS/calls.
2. **Component Integration**: Overcame hardware challenges (e.g., SIM800L network issues) by adopting a modular design, enabling seamless substitution of components.
3. **Effective Algorithms**: Implemented vector magnitude calculations for direction-independent crash detection and optimized GPS parsing for location accuracy (2.5m in open areas).
4. **Practical Design**: Maintained helmet integrity with lightweight enclosures (total weight <300g) and ergonomic component placement.
5. **Proven Reliability**: Achieved 88% SMS success rate on Airtel's 2G network and 92% crash detection accuracy in controlled tests.

10.2 Limitations

1. **Sensor Constraints**: ADXL345's ±16g range may miss severe impacts (>100g). GPS cold-start delays (~27 seconds) affect real-time location accuracy.
2. **Network Dependency**: Reliance on 2G networks limits coverage in remote areas and raises sustainability concerns as global 2G phase-outs continue.
3. **Incomplete Features**: Alcohol detection (MQ-3 sensor) failed due to voltage issues; minimal user interface restricts configurability.
4. **Power Management**: Basic battery system lacks sleep modes, limiting runtime (<24 hours continuous use).
5. **Environmental Sensitivity**: GPS struggles in urban/tree-covered areas; performance varies with temperature (10°C–40°C).

10.3 Social & Technological Implications

1. **Safety Impact**: Potential to reduce emergency response times by 10+ minutes, improving survival rates in accidents. Could boost helmet adoption rates through added tech incentives.
2. **IoT Integration**: Demonstrates feasibility of embedding IoT in safety gear, paving the way for smarter protective equipment (e.g., drowsiness detection).
3. **Infrastructure Challenges**: Highlights dependency on cellular networks and the need for hybrid solutions (e.g., Bluetooth/satellite fallbacks).
4. **Affordability**: Low-cost design (~$45) makes advanced safety accessible to riders across economic backgrounds.

10.4 Future Recommendations

1. **Hardware Upgrades**:
   - Replace ADXL345 with high-range accelerometers (e.g., ADXL377) and revive alcohol detection with voltage protection.
   - Migrate to ESP32 for better processing, Wi-Fi/Bluetooth, and power efficiency.
   - Add solar charging and smart power management.
2. **Software Improvements**:
   - Implement machine learning to distinguish crash types (minor vs. severe) and reduce false alarms.
   - Enhance GPS with A-GPS for faster fixes and cellular triangulation as backup.
   - Develop a companion app for real-time alerts, ride logging, and emergency service integration.
3. **Usability & Compliance**:
   - Streamline installation with modular housings and quick-connect wiring.
   - Add voice alerts, multi-color LEDs, and vibration feedback for intuitive interaction.
   - Ensure compliance with safety standards (e.g., EMC testing) and data privacy regulations.

4. **Broader Initiatives**:
    - Conduct field trials across diverse environments (urban, rural) to refine reliability.
    - Collaborate with helmet manufacturers for certified, factory-integrated designs.
    - Create open-source repositories to foster community-driven innovation.

10.5 Conclusion

The development of this smart helmet prototype marks a significant stride in leveraging IoT and embedded systems to address critical challenges in motorcycle safety. By successfully integrating impact detection, GPS localization, and emergency communication, the project demonstrates how affordable technology can transform passive safety gear into active life-saving systems. While current limitations in sensor range, network dependency, and power management highlight areas for refinement, the prototype’s core functionality—reliable accident detection and automated emergency alerts—proves the viability of smart helmets as a scalable solution for rider protection.

The project’s broader implications extend beyond technical implementation, underscoring the potential for IoT-enabled safety systems to democratize access to advanced protection across socioeconomic divides. As motorcycle accidents remain a leading cause of global fatalities, innovations like this emphasize the urgent need for adaptive, context-aware safety technologies that bridge gaps in emergency response infrastructure.

Future advancements, including machine learning for crash severity analysis, multi-network redundancy, and preventative features like alcohol detection, could elevate the system from a reactive tool to a comprehensive safety platform. Collaboration with helmet manufacturers, regulatory bodies, and urban planners will be crucial to mainstream adoption. Ultimately, this work not only provides a blueprint for next-generation rider safety but also serves as a compelling case study in how embedded systems can drive meaningful social impact—turning everyday safety gear into intelligent guardians capable of saving lives in the critical moments after an accident.

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