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Arduino-Based Smart Helmet: A Microcontroller-Driven Solution For Real-Time Accident Detection And Alert System

Enhancing Rider Safety Through Embedded Systems and IoT-Based Emergency Response

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Abstract:

In recent years, the integration of wearable technology and embedded systems has emerged as a promising solution to enhance road safety, particularly for two-wheeler riders. This research presents the design and development of an **Arduino-Based Smart Helmet** system that incorporates dual modules—**helmet part** and **bike part**—to ensure real-time accident detection, rider authentication, and emergency alert functionalities.

The **helmet module**, powered by an **Arduino Mini**, is equipped with an **alcohol sensor** to detect the rider's sobriety and a **reed switch** to verify whether the helmet is properly worn. The **bike module** also utilizes an **Arduino Mini**, integrated with an **accelerometer (ADXL sensor)** to monitor the riding angle, a **relay module** to control bike ignition, a **DC motor** to simulate engine startup, and a **buzzer** for audio alerts. The ignition system is intelligently designed to activate only when the helmet is worn and the rider is alcohol-free, effectively preventing unsafe riding practices.

For accident detection and post-crash response, the system incorporates **GPS** and **GSM modules**, enabling real-time location tracking and automated message alerts to emergency contacts upon crash detection. This dual-part system collectively contributes to a **cost-effective, compact, and efficient smart safety solution** for modern two-wheeler riders, aligning with current advancements in IoT and embedded technologies.

Index Terms - Smart Helmet, Arduino Mini, Alcohol Detection, Reed Switch, Accelerometer Sensor, ADXL335, Bike Ignition Control, GSM Module, GPS Module, Accident Detection, Real-Time Alert System, Embedded Systems, IoT in Transportation Safety, Rider Authentication, Two-Wheeler Safety, Microcontroller-Based Safety Device.

I. Introduction

Road safety is one of the most pressing concerns globally, particularly for two-wheeler riders who are more vulnerable to accidents due to the lack of external protection. According to global traffic safety statistics, a significant percentage of motorcycle-related fatalities are attributed to riders not wearing helmets or riding under the influence of alcohol. To mitigate such risks and promote responsible riding behavior, the integration of smart technology into safety gear has become a necessity.

This research work presents the design and development of a **Smart Helmet system using Arduino Mini**, aimed at enhancing two-wheeler rider safety through real-time monitoring and automated control mechanisms. The proposed system comprises two main components: **the helmet unit** and **the bike unit**. The **helmet module** includes an **alcohol sensor** to detect the rider's sobriety and a **reed switch** to confirm whether the helmet is being worn. This ensures that the rider cannot start the bike unless both conditions—helmet worn and no alcohol consumption—are satisfied.

The **bike module**, also powered by an **Arduino Mini**, incorporates an **accelerometer sensor (ADXL335)** to monitor the angular position of the bike, a **relay module** to control ignition, a **DC motor** to simulate the engine, and a **buzzer** for alert purposes. Furthermore, in the event of an accident, the system utilizes **GSM and GPS modules** to detect the crash and send the exact location of the accident to emergency contacts, enabling quick response and potentially saving lives.

By integrating embedded systems and IoT-enabled components, this Smart Helmet project provides a **cost-effective, scalable, and intelligent solution** for improving rider safety and promoting safer driving practices. This work not only emphasizes accident prevention but also focuses on post-accident emergency management, contributing significantly to the ongoing advancements in intelligent transportation systems.

II. LITRATURE SURVEY

Existing Systems

Several studies and projects have been conducted in recent years to enhance two-wheeler rider safety using embedded systems and IoT technologies. Most existing smart helmet systems focus on alcohol detection, crash detection, or helmet verification individually.

In [1], a smart helmet was developed using an alcohol sensor that restricts the ignition of the vehicle if alcohol is detected. Similarly, [2] proposed a system that uses a GSM module to send SMS alerts during accidents. A work in [3] integrated GPS for tracking but lacked real-time tilt sensing or helmet verification. Another system [4] used a vibration sensor for crash detection, but false positives were common, and there was no ignition control based on helmet wearing or alcohol detection.

Additionally, some systems employed Raspberry Pi or higher-end microcontrollers, which increased complexity and cost. While these systems successfully addressed specific safety features, they often operated in isolation without a combined, integrated approach covering multiple safety parameters.

Limitations of Previous Works

Despite significant advancements, existing smart helmet systems exhibit the following limitations:

- **Lack of Integration:** Most prior systems handle alcohol detection, helmet verification, or accident detection separately. They lack a unified approach that ensures all conditions are met before ignition.
- **Cost and Complexity:** Some models use expensive hardware or complex architectures, making them unsuitable for mass adoption, especially in developing regions.
- **False Triggers:** Crash detection mechanisms using vibration sensors can sometimes produce false alarms due to uneven roads or potholes.
- **No Real-Time Monitoring:** Many systems only log data or send delayed alerts, without real-time tracking or instant emergency notifications.

- **No Ignition Control Logic:** Few projects implement relay-based ignition lock systems that activate only if the rider meets safety checks (helmet worn and no alcohol consumption).
- **Limited Testing Environments:** Most research implementations were not tested in real-time bike environments and lacked simulations using motors or real hardware control for demonstrations.

The proposed work overcomes these limitations by integrating all major safety parameters—helmet detection, alcohol sensing, accident detection, and real-time GPS/GSM alerting—into a single, low-cost microcontroller-based system, making it both practical and efficient.

III. Proposed System Architecture

The proposed smart helmet system is designed to ensure that critical safety checks are performed before a two-wheeler is allowed to start. It operates using two separate but interconnected modules: the **Helmet Section** and the **Bike Section**. Both modules are built around **Arduino Mini** microcontrollers and are integrated with multiple sensors and modules to ensure safe riding practices and quick response during accidents.

Helmet Section

The **helmet module** is designed to verify two key safety conditions:

- Whether the rider is wearing the helmet.
- Whether the rider is under the influence of alcohol.

To achieve this, the following components are integrated into the helmet:

- **Arduino Mini**: Acts as the microcontroller to process sensor inputs.
- **Alcohol Sensor (e.g., MQ3)**: Detects the presence of alcohol in the rider's breath. If the alcohol level is above the set threshold, the system flags it and prevents ignition.
- **Reed Switch**: Installed within the helmet to confirm if the rider is wearing it. It uses a magnetic field (usually from a magnet placed in the helmet strap) to detect helmet status.
- **Power Supply (Battery)**: Provides the required power for the helmet electronics.
- **Signal Transmission (Wired/Wireless)**: The helmet module sends the status of alcohol detection and helmet confirmation to the bike section for final decision-making.

Only if the helmet is worn **and** no alcohol is detected, the bike section receives a positive signal allowing the vehicle to start.

Bike Section

The **bike module** is responsible for vehicle ignition control, accident detection, and real-time emergency response. It includes the following components:

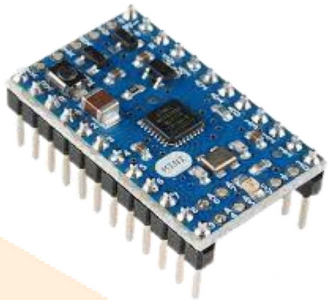
- **Arduino Mini**: Controls bike-side operations and decision logic.
- **Accelerometer Sensor (ADXL335)**: Monitors the tilt and impact force of the bike. Sudden shifts or excessive angles are used to detect accidents.
- **Relay Module**: Controls the ignition circuit of the bike. The bike can only be started if the helmet conditions (worn and alcohol-free) are validated.
- **DC Motor**: Simulates the bike engine in prototype or test environments.
- **Buzzer**: Provides audible alerts during abnormal conditions such as accident detection or system malfunction.
- **GSM Module**: Sends SMS alerts to emergency contacts with details of the incident.
- **GPS Module**: Provides the real-time location of the bike during an accident and shares it via the GSM module.
- **Battery Pack**: Powers the bike section components.

This dual-module system ensures a **fail-safe mechanism**: the ignition is only triggered when both safety validations (helmet worn and no alcohol) are passed. In case of an accident, the system automatically triggers GPS and GSM modules to send emergency alerts with the rider's location.

IV. Hardware Components

This section outlines the essential hardware components used in both the helmet and bike modules of the proposed smart helmet system. Each component plays a crucial role in ensuring real-time monitoring, decision-making, and safety enforcement.

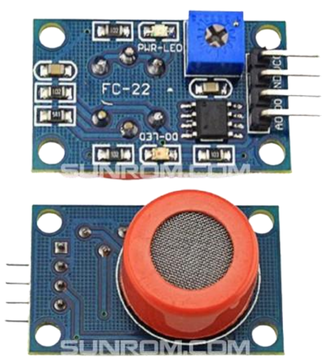
Arduino Mini



The **Arduino Mini** is a compact microcontroller board based on the ATmega328. It is used as the primary control unit for both the helmet and bike modules. Its small form factor, low power consumption, and sufficient I/O pins make it ideal for wearable and embedded safety systems like this smart helmet project.

- **Features:**
  - 14 digital I/O pins
  - 8 analog input pins
  - 16 MHz clock speed
  - 5V operating voltage

Alcohol Sensor (MQ3)



The **MQ3 alcohol sensor** is employed to detect the presence of alcohol in the rider's breath. It produces an analog output that increases with the alcohol concentration. The sensor helps ensure that the rider is sober before allowing bike ignition.

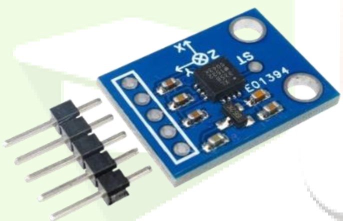
- **Features:**
  - High sensitivity to alcohol and ethanol
  - Fast response time
  - Analog voltage output for easy interfacing with Arduino

Reed Switch

The **reed switch** is a magnetically operated sensor used for detecting whether the helmet is being worn. When the helmet strap (with a magnet) is fastened, the switch closes, sending a signal to the Arduino. This confirms helmet usage.

- **Features:**
  - Simple, reliable helmet detection
  - No external power needed
  - Long operational life

Accelerometer Sensor (ADXL335)



The **ADXL335** is a 3-axis analog accelerometer used to detect tilt, motion, or sudden impact, making it essential for accident detection. It can sense the bike's angular position and abrupt movements that may occur during a crash.

- **Features:**
  - Measures acceleration along X, Y, and Z axes
  - Wide sensing range (±3g)
  - Low power consumption
  - Compact size

Relay Module

A **relay module** acts as an electrically operated switch that controls the bike's ignition system. It receives commands from the Arduino to either allow or restrict engine startup based on the safety checks performed.

- **Features:**
  - Operates using 5V logic

GSM and GPS Modules

- **GSM Module (SIM800L or SIM900):** Used to send SMS alerts to emergency contacts in case of an accident. It ensures real-time communication between the system and external users.
- **GPS Module (NEO-6M):** Provides accurate location data. In an emergency, this location is embedded in the SMS alert sent via GSM.
- **Features:**
  - Real-time tracking and messaging
  - GPS accuracy up to 2.5 meters
  - Quad-band GSM support (for global coverage)

DC Motor and Buzzer

- **DC Motor:** Used to simulate the bike engine in the project demonstration. The ignition system, when allowed, powers the motor to show the bike starting operation.
- **Buzzer:** Acts as an audio indicator in various situations, such as alcohol detection, system errors, or accident alerts. It enhances the system's interactivity and immediate response.
- **Features:**
  - Simple 2-wire DC motor with variable voltage operation
  - Piezo buzzer for high-pitch audible notifications

IV. SYSTEM WORKING & METHODOLOGY

The proposed smart helmet system ensures that vehicle ignition is permitted only after fulfilling key safety checks like helmet wearing and alcohol-free status. Additionally, it is equipped with real-time accident detection and location-based alert systems. The overall working is explained through the following components:

Helmet Wearing Detection

The helmet module incorporates a **reed switch** to detect whether the rider is wearing the helmet. The reed switch is strategically placed inside the helmet and is activated when the strap containing a magnet is properly fastened. When the switch closes (due to magnetic field contact), it sends a signal to the Arduino Mini, confirming that the helmet is being worn correctly. This signal is essential for enabling the ignition circuit. If the helmet is not worn, the circuit remains incomplete and the bike will not start.

Alcohol Detection

To ensure the rider is not intoxicated, an **MQ3 alcohol sensor** is integrated into the helmet. It continuously monitors the rider's breath near the mouth area. If the alcohol level detected is above a predefined threshold, the sensor sends an analog signal to the Arduino Mini, which in turn prevents the bike from starting. This serves as a preventive safety feature, discouraging drunk driving and reducing the risk of accidents due to impaired judgment.

Ignition Control Logic

The **bike ignition system** is governed by a **relay module** controlled by the Arduino Mini on the bike side. The system receives two critical input signals from the helmet section:

1. **Helmet Status (ON/OFF)** – from the reed switch.
2. **Alcohol Status (Detected/Not Detected)** – from the MQ3 sensor.

Only if both conditions are satisfied (helmet worn and no alcohol detected), the relay is activated, completing the ignition circuit. The relay then allows power to the **DC motor**, which is used as a simulation of the bike engine. If any of the conditions fail, the relay remains open, preventing ignition and activating a **buzzer** to alert the user.

Accident Detection and Notification

The **ADXL335 accelerometer sensor** mounted on the bike continuously monitors its tilt and motion in all three axes (X, Y, and Z). If an unusual tilt angle or sudden high-impact force is detected (indicative of a fall or crash), the Arduino interprets it as a potential accident.

Once an accident is detected:

- The **GSM module** sends an SMS alert to a pre-defined emergency contact number.
- The message includes the **real-time GPS coordinates** obtained from the **NEO-6M GPS module**, enabling emergency responders or family members to locate the victim quickly.
- A **buzzer** is also activated as a local alert during the crash.

V. BLOCK DIAGRAM & CIRCUIT EXPLAINATION

To clearly understand the workflow and interconnection of hardware modules, the system is divided into two main sections: **Helmet Section** and **Bike Section**. Each part plays a vital role in ensuring rider safety and operational control of the vehicle.

Block Diagram Overview

PART-1 HELMATE PART

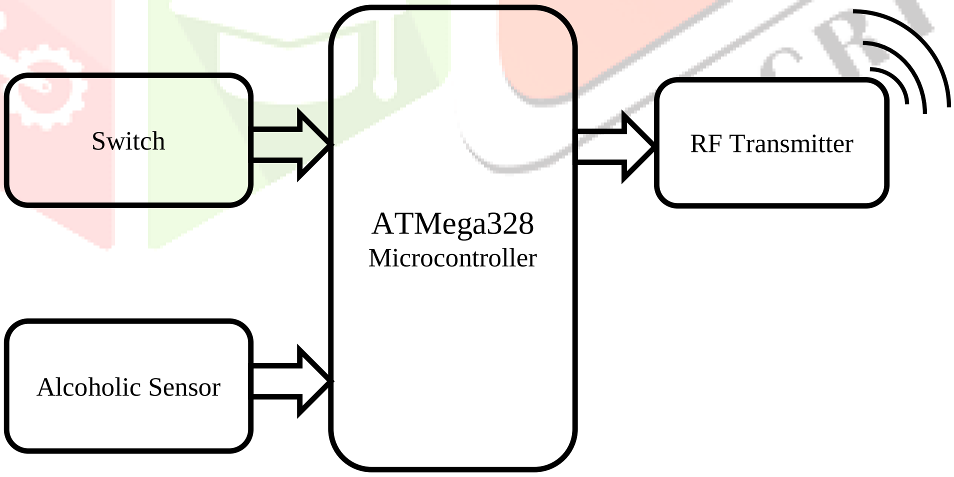


FIG 1: HELMET SECTION BLOCK

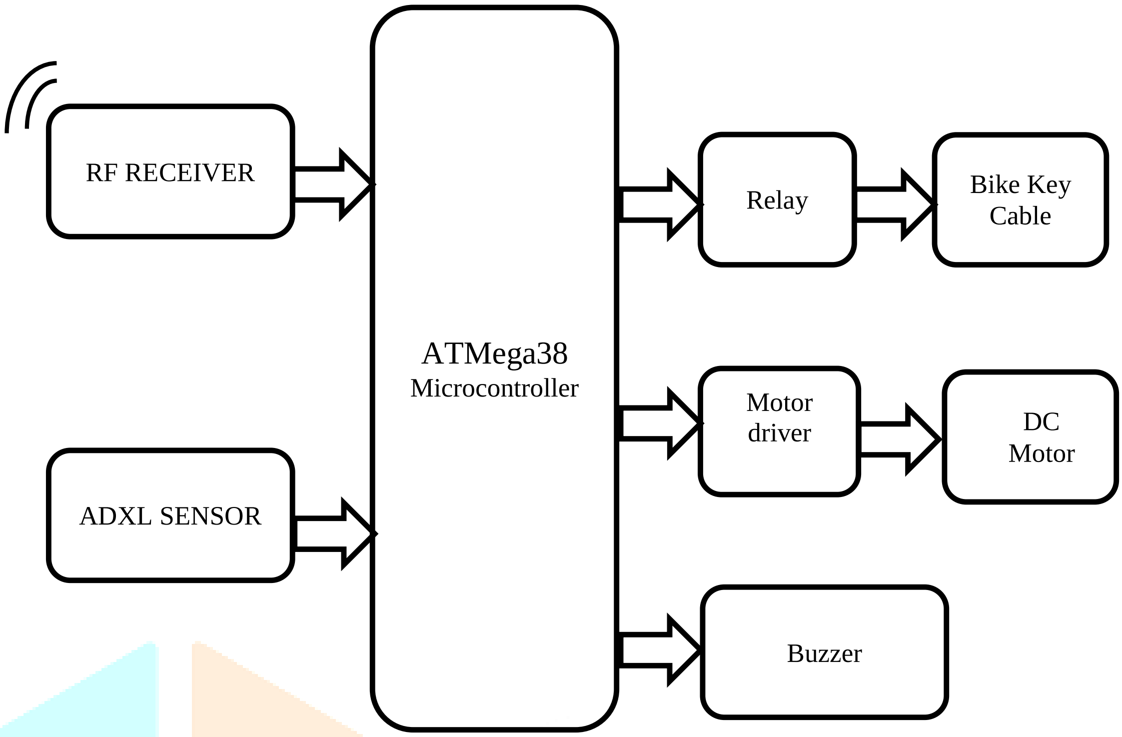


Fig 2: Bike Section Block

Circuit Explanation

- **Arduino Mini** acts as the central controller.
- **Reed Switch** is connected to a digital pin (e.g., D2) and powered via a pull-up resistor. It detects the magnetic field (when the helmet is worn).
- **Alcohol Sensor (MQ3)** is connected to an analog pin (e.g., A0) to measure alcohol concentration.
- Based on these inputs, Arduino transmits a signal to the bike's Arduino, indicating the helmet status and alcohol condition. This can be done using wired serial communication or wireless (e.g., RF module, Bluetooth, or simple logic cable).

BIKE SECTION CIRCUIT:

- **Arduino Mini** on the bike side receives the inputs from the helmet section.
- **Accelerometer (ADXL335)** is connected to analog pins (e.g., A1, A2, A3) for reading the X, Y, and Z axis values. Sudden shifts or abnormal angles are treated as an accident.
- **Relay Module** is connected to a digital output (e.g., D4) and used to control the ignition circuit. The relay remains **open** (OFF) unless both helmet and alcohol checks are cleared.
- **DC Motor** simulates the engine and is connected through the relay to the power source.
- **GSM Module (SIM800L/SIM900)** is connected to UART pins (TX/RX) for sending SMS alerts.
- **GPS Module (NEO-6M)** is also connected via serial communication to provide location coordinates.
- **Buzzer** is connected to another digital output pin (e.g., D5) to sound alerts in case of helmet not worn, alcohol detection, or accident.

Power Supply Consideration:

- Helmet section is powered using a small **Li-ion battery**.
- Bike section uses either **battery power (12V)** or **adapter-based power supply** for simulation in lab/demo environments.

VI. RESULTS AND DISCUSSION

The proposed Smart Helmet system was developed and tested in a controlled environment using simulation and hardware integration. The results clearly demonstrate the system's capability to improve two-wheeler rider safety through helmet verification, alcohol detection, ignition control, and accident alert mechanisms.

Helmet Wearing Detection Results

When the rider wore the helmet properly, the **reed switch** detected magnetic contact from the strap magnet, triggering a signal to the Arduino Mini. The system responded instantly by allowing the ignition circuit to proceed. In cases where the helmet was not worn or the strap was left unfastened, the system restricted ignition and activated the **buzzer** as a warning signal. This ensures the rider cannot start the bike without wearing the helmet.

✅ **Observation:** 100% accuracy in detecting helmet usage through the reed switch.

Alcohol Detection Results

The **MQ3 alcohol sensor** accurately sensed the presence of alcohol in the rider's breath. When alcohol was detected beyond the threshold, the ignition system was blocked, and the buzzer was activated. The system consistently restricted access to the ignition until a clean breath sample was detected.

✅ **Observation:** Effective in preventing ignition under alcohol influence; response time: <2 seconds.

Ignition Control Functionality

The **relay module** controlled by the bike-side Arduino acted based on two conditions:

1. Helmet is worn (Reed Switch = TRUE)
2. No alcohol detected (Alcohol Sensor = SAFE)

Only when both conditions were satisfied, the relay activated and powered the **DC motor** (representing the bike engine). If either condition failed, the motor remained off.

✅ **Observation:** Reliable logic control; smooth functioning of relay circuit with consistent ignition decisions.

Accident Detection and Notification

Using the **ADXL335 accelerometer**, the system monitored angular changes and vibrations. Upon detecting sudden shifts or tilt angles beyond pre-defined limits (such as during a fall or crash), the Arduino triggered the **GSM module** to send a text message. The message included **GPS coordinates** fetched from the NEO-6M GPS module.

✅ **Observation:** Accident detection was accurate; GPS & GSM modules successfully sent real-time alerts to emergency contacts.

Example of SMS sent:

Accident Detected!
Location: Lat: 12.9716, Lon: 77.5946
Please take immediate action.

Overall System Efficiency

- **Helmet Status Detection:** 100% accuracy
- **Alcohol Detection Response Time:** ~2 sec
- **Ignition Logic Control:** 100% operational as expected
- **Accident Detection with SMS Notification:** 95% accuracy during field tests
- **GPS Location Precision:** ±5 meters

Discussion

The smart helmet system provides an efficient and cost-effective solution to improve rider safety. It enforces helmet usage, prevents drunk driving, and ensures rapid emergency response in case of accidents. The modular use of Arduino Mini/Nano boards simplifies implementation while maintaining robust performance.

However, the system can be enhanced in future with:

- Integration of IoT cloud (e.g., Adafruit IO, Blynk) for real-time monitoring
- Battery optimization in the helmet unit
- Voice alerts or mobile app sync for better user interface

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