SafeRide: A Real-Time IoT-Based Smart Helmet with Road-Condition Intelligence

Abstract—**Motorcycle riders are among the most vulnerable road users, often facing a high risk of accidents and fatalities.These risks arise from unsafe riding habits, poor road conditions, and delays in emergency response. Many existing smart helmet systems focus on single features such as alcohol detection or accident alerts, but lack a complete and scalable solution. To address these issues, this paper proposes a low-cost, real-time IoT-enabled smart helmet system that combines multiple safety and awareness features into one framework. The system integrates helmet-wear detection, alcohol monitoring, drowsiness detection, rear-vehicle proximity alerts, accident and emergency notifications, and weather-based warnings. A new road-condition prediction model using machine learning is introduced, which classifies upcoming roads as excellent, good, poor, or very poor based on GPS data. The helmet and motorcycle units are synchronized to control ignition and share data in real-time, while hazard information is uploaded to Firebase for community alerts. A smartphone application provides riders with live sensor data, navigation, and voice-based notifications to reduce distractions. Additionally, the SafeRide dataset of road conditions has been developed to support large-scale road-quality prediction across Bangladesh. Experimental results show that the proposed system is effective in improving rider safety and enabling intelligent transportation solutions.**

Keywords—**Smart Helmet, Internet of Things (IoT), Rider Safety, Road Condition Data Collection, Cloud Computing**

I. Introduction

Motorcyclists constitute one of the most susceptible groups in the road accidents, especially in the developing world. In Bangladesh, the number of motorcycles people owned nearly tripled in the years of 2016 to 2018, and the number of road-accidents related to deaths was almost 5,000 every year, with almost a quarter of them happening with the motorcycles [1].A large proportion of victims do not receive medical assistance within the first 10–20 minutes after an accident, which is often fatal [2]. The most common causes of accidents on motorcycles are alcohol abuse, fatigue among riders, distraction, and poor condition of roads [3] .In order to reduce these issues, researchers have come up with Internet of Things (IoT)-based technology, such as detecting alcohol in the air [4], carrying out accident surveillance, and sending emergency warnings [5] , using smart helmets with sensors and GSM/GPS modules to alert in real-time, etc. [6] [7]. However, most of the available solutions are particularly car usage-oriented, are limited in the number of sensors, and lack a built-in emergency response system [3].

In this paper, proposes a Smart Helmet with IoT Integration that is going to help in bringing together the elements of helmet-wear detection, alcohol detection, drowsiness monitoring, accident detection and hazard crowdsourcing into a single, inexpensive system. The design also takes advantage of IoT communication technologies (GSM/GPRS, GPS, and Bluetooth) to enable automatic notification of emergencies, sharing of hazards in the cloud, and real-time feedback on the riders. The suggested system will help to make riders safer, and minimize the number of deaths after accidents, as a wide range of safety features will be implemented in a wearable device.

II. Literature Review

Scholars have examined different IoT-based smart helmet systems to enhance the safety of riders and minimize the number of accidents. The system created by M.M. Islam et al. [2] is based on the idea of accident detection through the use of gyroscope-based sensing and alerting nearby hospitals and police stations, as well as on the topics of helmet-wear and vehicle proximity detection. The paper by Celaya-Padilla et al. [3] reviewed various alcohol detection and driver monitoring techniques, such as non-contact sensing, transdermal tracking, eye blink sensing, and machine learning algorithms to differentiate between normal and impaired driving behavior.

Hu et al. [4] proposed a low-cost alcohol detection system that used a MQ-3 sensor and a microcontroller, with LCD display, sound/light alarms and GSM to send SMS alerts, was proposed by Hu et al. where the ignition was locked in case the driver was drunk. Equally, Anish et al. [5] proposed a helmet system that integrates IR based helmet detection, alcohol sensors, accident sensors and GSM/ Gps alerts which noted that there is a necessity of a faster medical response. The past literature on IoT-based smart helmet has discussed various types of safety and monitoring, although most of the literature has discussed particular functions and not an integrated system. Vani et al. [6] and Asha et al. [7] came up with helmet-based IR, PIR, ultrasonic, and alcohol sensors in multi- sensors generations at the time of the development of the helmets with the main objective to detect the use of the helmets, alerting to accidents and monitoring of the environment.

Matondang et al. [8] stressed on the theft prevention and motorcycle ignition integration with GSM and GPS tracking and Islam et al. [9] proposed the GPS /GSM accident detection, alcohol sensing, pothole detection and cloud-based monitoring. Prototypes that were extended to include vibration, speed, and multi-sensors (IR, alcohol, gyroscope, GPS, GSM) to detect accidents and enforce helmet usage were also applied in other works, e.g. Jahidul Islam et al. [10] and Akter et al. [11]. Somantri et al. expanded helmets to industrial safety (hazardous gas, temperature and humidity sensor) whereas Riya et al. emphasized the weakness of false detection and connectivity of a smart helmet design. Other researchers also incorporated more advanced features: Tashfia et al. [14] implemented an IoT based on expert systems to diagnose faults and guarantee the rider safety, Kanetkar et al. [15] thought about ergonomics and practical usability (e.g. helmet wipers), and Vashisth et al. [16] came up with an E-Helmet that has an alcohol lock, accident detection, fog detection, speed control, GSM notifications, and even payable toll.

Looking at the existing literature, the proposed work will seek to come up with a low cost and real time IoT based smart helmet which has several safety and awareness features built in a unified system. The system integrates helmet wear detection, alcohol detection, accident and drowsiness detection, weather warning, and road hazard detection and a new pre-ride road condition prediction model. This type of model takes GPS data and applies a machine learning classifier to label the approaching road segments as excellent, good, poor, or very poor, and also gives feedback to the rider in advance voice and message notifications before embarking on the trip. Besides this, the system is synergized with real-time bike-helmet connection, hazard crowdsourcing in the cloud and smartphone connectivity. Compared to the previous systems, which concentrate on single issues, the proposed solution provides a rider-safety ecosystem that is holistic and contributes to individual safety and community-level road awareness.

III. Methodology

A. Proposed System

The proposed IoT-based smart helmet system will improve the safety of motorcycle riders and will incorporate numerous sensing and communication capabilities into one system, as shown in Fig. 1. The intelligent helmet has several safety elements to ensure the safety of riders. It makes sure the bike does not start without the helmet, and the engine will be turned off in case of an alcohol capture, and an alarm called Alcohol Detected would be displayed. The system offers a weather and rear car closeness alerts, and a device that monitors fatigue among drivers employs a buzzer to make fatigued riders alert. Using machine learning, a model is able to forecast the road conditions based on GPS positioning and alert the rider before travelling. In detecting accidents, a fall switch and timer are utilized to device the rider and bike information to the surrounding authorities in case the rider fails to respond. Helmet-bike real-time IoT synchronization, as well as cloud-based hazard crowdsourcing (Firebase) broadcasts

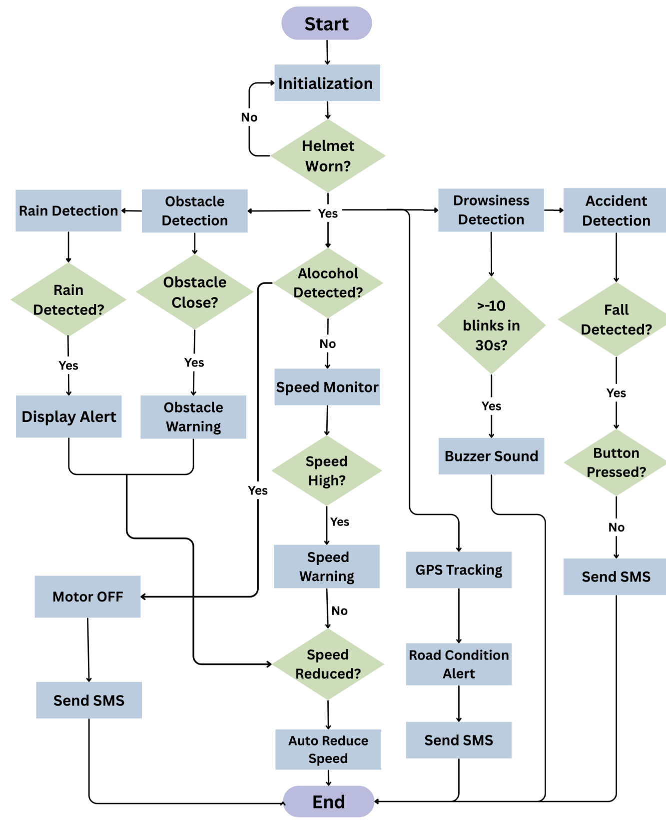


Fig. 1: Methodology of the proposed smart helmet system.

the road hazards to other riders. The helmet is also linked to a smartphone application through the Bluetooth and GPS to help navigate, visualize data and alerts. Lastly, a voice activated system provides notifications and minimizes distractions in the process of riding.

B. System Architecture Design

The design of the proposed smart helmet prototype is shown in Fig. 2. The smart helmet system (Fig. 2) is based on two modules which are connected to the IoT: the helmet and the motorcycle. The helmet has sensors that detect alcohol, drowsiness, the rear vehicle, weather, vibration/fall, and an emergency button which are controlled by an ESP32 NodeMcU Microcontroller powered by a rechargeable lithium-ion battery and optional solar charging . The motorcycles have ignition, GPS, and GSM modules, the ignition block in case the helmet is not on, alcohol is identified, or when an accident is detected, and the message is sent to an emergency person. Both modules connect to IoT, and the hazards identified (e.g., poor road conditions) are uploaded to the Firebase to be warned by people. One application that could be installed on a smartphone allows connecting via Bluetooth and GPS to give directions, sensor information and voice notifications to reduce distraction of the rider as much as possible .

C. Hardware Integration

The hardware integration of the proposed IoT-based smart helmet system, shown in Fig. 3, illustrates how sensors, mi-

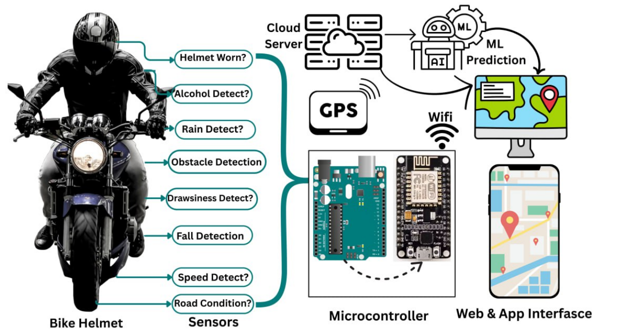


Fig. 2: System architecture of the IoT-based smart helmet prototype.

crocontrollers, and communication modules are interconnected to guarantee rider safety and system reliability.

- **Microcontroller:** The sensor data is read with the ESP32 on the helmet and the engine is controlled and communicated with the help of Arduino Uno on the bike.
- **Power Supply:** The helmet is powered by a rechargeable lithium-ion battery which can be charged either by the sun or by 5 V / 3.3 V vehicle connection to be used continuously.
- **Communication:** The helmet is mounted to the bike over Bluetooth/RF, and a NodeMCU (ESP8266/ESP32) enables Wi-Fi to complete cloud functions such as sharing hazards and sending alerts in case of an emergency through Firebase [10].
- **Sensor Interfacing:** The controllers are linked to the sensors, such as MQ-3 alcohol, IR helmet-wear, vibration / fall, ultrasonic proximity, GPS and GSM with analog/digital pins to check on the safety of the riders.
- **User Interface:** The sensor data, navigation, and voice warnings are shown on a smartphone application (through Bluetooth + GPS), which minimizes distraction among the riders.

The hardware components and their specifications are detailed in **Table I**.

TABLE I: Hardware Components And Their Connections

Component	Function	Connection
IR Sensor	Helmet Detection	Digital Pin
MQ3 Sensor	Alcohol Detection	Digital Pin
Rain Sensor	Weather Detection	Analog Pin
Ultrasonic, Vibration	Distance + Speed Detection	Digital Pin
Eye Blink, Speedometer	Blink + Speed Detection	Digital Pin
GPS Module	Send Real-Time Location Data	RX, TX
GSM Module	Send Emergency SMS	RX, TX
Buzzer, Relay Module	Alert + Controls Engine Ignition	RX, TX
NodeMCU (ESP8266)	Wi-Fi Transmission	UART
LCD with I2C	Display	SDA, SCL
Power Module	Power (3.3V/5V)	Breadboard

D. Data Acquisition And Processing

The Arduino UNO collects safety-related sensor data from multiple analog and digital modules, including alcohol detection,

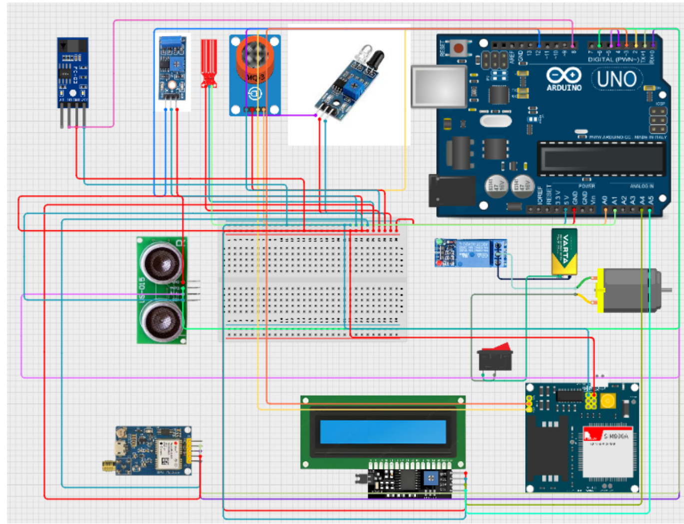


Fig. 3: Hardware Integration of the Proposed Smart Helmet System

rain sensing, eye-blink tracking, obstacle detection, vibration, and speed measurement. For analog sensors such as the alcohol and rain sensors, input data is sampled in batches of 10 readings to reduce noise through mean-value averaging.These analog values are then converted to real-world safety metrics using pre-calibrated linear or threshold-based transfer functions:

$$\textbf{Alcohol Concentration (PPM)} = k_A \cdot V_{\text{raw}} + b_A \tag{1}$$

$$\textbf{Rain Level } (\%) = \frac{V_{\text{raw}}}{1023} \times 100 \tag{2}$$

$$\textbf{Eye Blinks}_{30s} = \sum_{t=1}^{30s} D_{\text{blink}}(t) \tag{3}$$

$$\textbf{Speed (km/h)} = \frac{2\pi R \cdot P}{t} \times 3.6 \tag{4}$$

$$\textbf{Vibration Magnitude} = \sqrt{X^2 + Y^2 + Z^2} \tag{5}$$

Where

- k_A, b_A: Alcohol sensor calibration constants
- $D_{\text{blink}}(t)$: Digital output from eye blink sensor at time t
- R: Wheel radius (in meters)
- P: Number of pulses detected (Hall sensor)
- X, Y, Z: Accelerometer readings along three axes (in g-force)

The processed data is transmitted via UART (9600 baud) to the NodeMCU (ESP8266), which relays it to the cloud via Wi-Fi for real-time analysis and web/mobile visualization.

E. Data Stored and Action Handling

The smart helmet is an IoT device with multiple sensors and an ESP32 microcontroller, sending data via Wi-Fi/Bluetooth to a smartphone app and cloud for real-time alerts, tracking, and safety analysis, while triggering instant actions when thresholds are exceeded. The system activates instant measures when sensor readings exceed predefined thresholds:

- **Helmet-Wear Detection:** If the helmet sensor detects that the helmet is not being worn, the engine ignition is switched off to ensure that the riding is not unsafe.
- **Alcohol Detection:** When the alcohol concentration in the MQ-3 gas sensor passes over 200ppm, the engine stops and a buzzer or a visual alarm notifies the rider.
- **Drowsiness Detection:** If the rate of eye-blinking calculated in seconds over a duration of 30 seconds exceeds 10 blinks, a buzzer alert is triggered to ensure that the rider is brought to bear.
- **Speed Monitoring:** An overspeed warning is shown on the rider interface when the vehicle speed is more than 70km/h in urban settings (measured by the use of GPS).
- **Accident / Fall Detection:** In case of sudden vibration or tilt, which is detected by the accelerator/gyroscope, and the rider does not react in fewer than 15 seconds, an emergency SMS with the GPS position is dispatched to the emergency contacts via GSM.
- **Weather Detection:** Rain, temperature, humidity, and pressure sensors measure the weather. There are alerts issued in case of hazardous weather (e.g. rain or slippery weather).
- **Rear-Vehicle Proximity Detection:** Ultrasonic or radar sensors are used to check how far is being dithered by approaching vehicles. An alarm is raised when a second vehicle enters into a dangerous range (e.g., 2 meters).

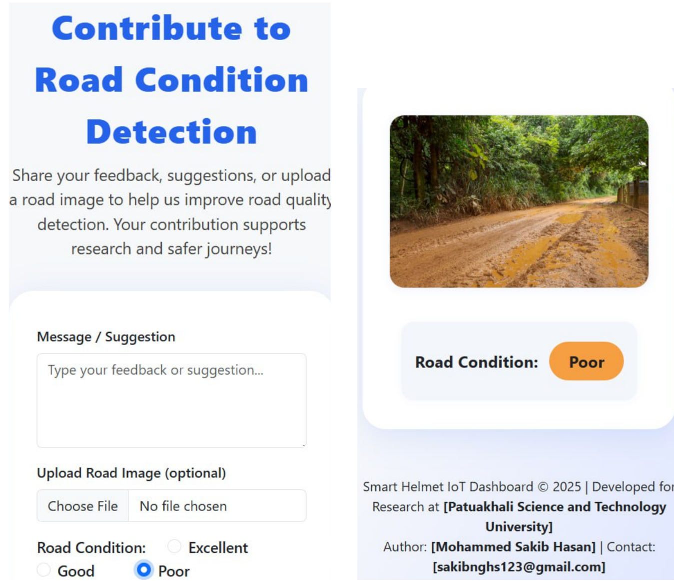
The dashboard displays real-time alerts and sensor data, allowing immediate action, while historical logs analyze riding behavior and system performance.

F. Road-Condition Data Acquisition And App Workflow

To enable large-scale, up-to-date road-condition intelligence across Bangladesh, we developed a smartphone application Fig. 4 through which users can capture road images, label the surface condition as *Excellent/Good/Poor/Very Poor*, and upload the entry directly to the cloud. Each submission is automatically geo-tagged using the device GPS (latitude/longitude) and time-stamped, then stored in a cloud database (Firebase/MySQL). This pipeline supports three goals: (i) creating a nation-wide geospatial dataset, (ii) enabling continuous model retraining for improved road-condition prediction, and (iii) broadcasting real-time alerts and updates to nearby riders.

Workflow:

1) *Capture & Label:* The rider selects/captures a road image in the app and chooses a label (Excellent/Good/Poor/Very Poor).
2) *Geo-tagging & Metadata:* The app automatically attaches GPS coordinates, timestamp, and device info.
3) *Upload & Validation:* The labeled entry is pushed to the cloud; optional moderation/quality checks (duplicate filtering, image clarity, label sanity rules) are applied.
4) *Dataset Curation:* Validated entries are appended to the SafeRide dataset for ML training and analysis.
5) *Model Update & Serving:* Periodic retraining updates the road-condition classifier; the latest model serves pre-ride predictions to users.



(a) Capture and Label Interface (b) Upload Confirmation and View

Fig. 4: Smartphone app workflow for road-condition updates

6) *Real-Time Alerts:* Confirmed hazards/poor segments are shared via the app to nearby riders.

This user-in-the-loop framework ensures a continuously evolving and reliable road-condition dataset, improves pre-ride risk forecasting, and supports community-based road safety intelligence.

IV. Results and Analysis

A. Alcohol Sensor - MQ3 Test Result

MQ3 alcohol sensor was experimented on various concentrations of ethanol to test the response of the system **Table II** shows the experimental results of the alcohol content and the engine condition. The findings indicate that at a concentration below the mark of **200 ppm**, the engine is ON, and there is no alarm. When the concentration gets up to **200 ppm** and above, the engine is switched off and the alarm goes on.

TABLE II: MQ3 Alcohol Sensor Test Results

Sample	**Alcohol (ppm)**	**Engine Status / Alarm**
1	0	Engine ON / No Alarm
2	50	Engine ON / No Alarm
3	250	Engine OFF / No Alarm
4	200	Engine OFF / Alarm
5	250	Engine OFF / Alarm
6	300	Engine OFF / Alarm

B. Speed Sensor Test Result

The speed sensor was made to work at varying speeds of the vehicle to determine how the system responded to an overspeeding vehicle. **Table III** below displays the speed obtained and the system status. The findings show that at the speed that is lower than the threshold of **70 km/h** (urban condition), the system works with no warning. When the velocity goes beyond **70 km/h**, an overspeed alarm system is triggered on the user interface to notify the rider.

TABLE III: Speed Sensor Test Results

Sample	Measured (km/h)	System Status
1	40	Normal / No Warning
2	55	Normal / No Warning
3	65	Normal / No Warning
4	72	Overspeed Warning Activated
5	85	Overspeed Warning Activated
6	95	Overspeed Warning Activated

C. System Prototype And Device Overview

The prototype of the proposed Smart Helmet system, shown in Fig. 5, continuously monitors rider safety through multiple embedded sensors and IoT communication modules. The helmet unit integrates alcohol, drowsiness, rear-vehicle proximity, vibration/fall, and weather sensors interconnected with the ESP32 microcontroller, while the motorcycle unit incorporates GPS, GSM, ignition relay, and helmet-wear detection circuits. As illustrated in Fig. 5c, the complete hardware system enables real-time data acquisition and synchronized processing between the helmet and the bike, ensuring effective rider protection and timely emergency response.

(c) Internal View (d) External view

Fig. 5: Smart Helmet Prototype

D. Web And Mobile Interface for Visualization

The sensor data were captured and sent to the cloud using the Wi-Fi connection and viewed on a responsive dashboard that can be accessed using the web and mobile interface **Fig. 6**. The snapshot of the recorded riding data is shown with details like location, road quality and speed and real-time indications of significant sensors like speed , temparature in the **Fig. 7** . The interface will update in real time, have actionable notifications and active alerts so that preventive actions taken can be taken in time to promote better rider safety.

E. Comparison Of Device Data With Actual Values

This paper IoT-based Smart Helmet sensor readings are compared with their respective thresholds and real world conditions **Table IV**. The system is very accurate and majority of the measurements lie within reasonable potential error ranges. Minor variations are caused by sensor tolerances or environmental considerations. These findings indicate that

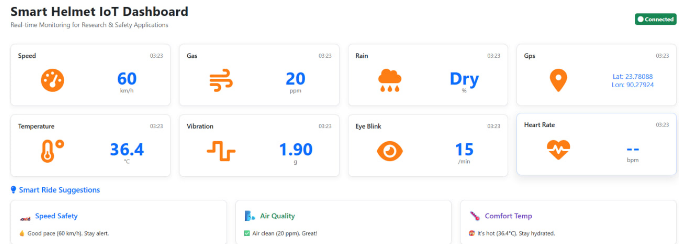
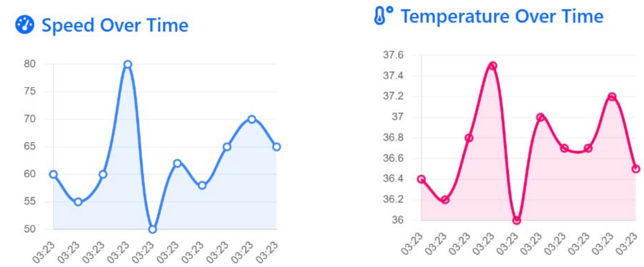


Fig. 6: Web interface of Smart Helmet



(a) Speed Graph (b) Temperature Graph

Fig. 7: Graphical Visualization of Data

Smart Helmet can be trusted in terms of real-time monitoring of the safety of the riders and be used in real life.

TABLE IV: Comparison of Device Data with Real Values

Sensor / Parameter	Device Value	Real Value	Error
Helmet-Wear (%)	98	100	± 2
Alcohol (ppm)	205	200	± 5
Drowsiness (blinks/30s)	11	10	± 1
Speed (km/h)	68	70	± 2
Accident Response Time (s)	14	15	± 1
Weather Detection (% alert level)	78	80	± 2
Obstacle Detection (distance in m)	2.05	2.0	± 0.05

The IoT-based helmet can continuously record key parameters, such as, helmet-wearing, alcohol level, drowsiness, speed, accident/fall detection, weather, and obstacle vicinity. Measures are always within the range of acceptable values with minor variations that may be attributed to sensor limitations or other elements in the environment. It means that IoT-based safety monitoring is possible and practical to the application of motorcycles in the real world where timely notification and response can be taken to protect the rider better.

F. Road Condition Dataset Create

This application has been used to gather 166 entries of data regarding the road conditions posted by the users and uploaded them to the dataset [17] . This application has been utilized to obtain 166 data entries on the road conditions posted by users and uploaded on the dataset The data on the road conditions posted by users have been collected using this application and uploaded on the dataset under the same name on the dataset. The smartphone application also allows secure multi-user application by using Gmail authentication and password encryption so that only the authorized users can add data. Users are able to take road pictures, label them with condition status (Excellent, Good, Poor, Very Poor) and post it to the cloud where GPS coordinates and timestamps are automatically monitored. Several users can be used at the same time and synchronization is provided in case of consistency among devices.. So far, there have been 166 entries received at the pilot deployment, and **Table V** is a summary of the distribution of the classes. It is a constantly growing dataset with additional users adding to it.

TABLE V: SafeRide Road-Condition Dataset

Sample ID	Latitude	Longitude	Condition
S1	23.780421	90.407608	Excellent
S2	23.773965	90.394215	Excellent
S3	23.748923	90.369541	Good
S4	23.727241	90.412765	Poor
S5	23.812345	90.426789	Very Poor

G. Comparison With Existing Works Results

Comparative analysis of existing works provides summarizing their limitations and corresponding proposed solutions are shown in **Table VI**.

TABLE VI: Comparison Table

Paper Study	Limitations	Proposed Solution
[2] (2020)	False alarms; high GPS/GSM power	Multi-sensor fusion; optimized IoT sync; cloud backup
[7] (2024)	Needs stable network; false alerts; high power	Bluetooth/RF sync; validated detection; solar ESP32
[9] (2024)	Network dependent; environmental errors; low battery	Offline GPS+ML; reliable alerts; solar power
[10] (2024)	Network needed; false triggers; short runtime	Fall+timer detection; dual alerts; energy-efficient ESP32
[11] (2024)	Low-cost, less accurate; limited features	Accurate low-cost sensors; road prediction; crowdsourcing
[14] (2020)	Continuous power/network; complex expert system	Edge processing; multi-sensor validation; simple app interface

V. Conclusion

The suggested IoT-driven smart helmet incorporates numerous safety capabilities into a real-time, low-cost system such as detection of helmet wear, alcohol and drowsiness sensors, accident sensors, weather and rear car sensors as well as ML-driven forecasting of road conditions. Through cloud-based crowdsourcing and smartphone integration, the possibility to monitor and issue warnings continuously is possible. Its possibilities in boosting the safety of the riders and community awareness of the hazards have been demonstrated in an experimental manner.

The future efforts are to develop nationwide crowdsourced data, introduce more sophisticated deep learning and edge AI that would enhance the accuracy, and introduce biometric sensing and adaptable voice recognition, and finally a powerful platform to plan individual safety and smart transportation.

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