Smart Safety Features for Motorcyclists' Safety Using IoT: Integrated Blind-Spot Monitoring, Forward-Collision Alerts, and Crash Detection with Real-Time Notification

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Abstract

Motorcycle riders, particularly delivery and courier riders, face elevated crash risk due to high road exposure, dense traffic, and time pressure. This paper presents a low-cost IoT-enabled motorcycle safety prototype integrating (i) blind-spot monitoring, (ii) forward-collision alerts, and (iii) crash detection with real-time notification. Pre-crash functions use ultrasonic ranging to detect nearby vehicles/objects and provide immediate warnings through side LEDs and an audible buzzer. Post-crash detection uses an ESP32 with inertial sensing and GPS to detect severe events and transmit alerts to an IoT dashboard and email contact. A working prototype was developed and evaluated through controlled tests for proximity detection and crash-event triggering, demonstrating consistent warning behavior and successful notification with location reporting. The design provides a practical retrofit pathway toward improved rider safety using affordable components and a modular architecture.

Keywords: Motorcycle safety; IoT; crash detection; blind-spot monitoring; forward-collision warning; ultrasonic sensor; MPU6050; ESP32; GPS; emergency notification

1. Introduction

Motorcycle crashes remain a major road-safety concern, and riders performing delivery services are exposed to traffic hazards more frequently due to long operating hours and repeated trips. Two urgent needs appear in many incidents: (1) reducing collision likelihood through early warnings, and (2) ensuring fast post-crash assistance through immediate alerting with accurate location. A practical safety solution should therefore provide real-time warnings during riding while also supporting emergency response if a crash occurs.

This work proposes an integrated IoT-enabled prototype combining two pre-crash functions and one post-crash func- tion:

- **Blind-Spot Monitoring (BSM):** rear-side proximity de- tection with left/right LED indicators to warn the rider of objects in adjacent zones.
- **Forward-Collision Alert (FCA):** frontal proximity de- tection using ultrasonic ranging and an audible buzzer warning.
- **Crash Detection and Notification:** IMU-based crash- event detection with GPS coordinate acquisition and alert delivery via dashboard and email.

A. Contributions

The contributions of this paper are:

- A low-cost integrated design for BSM, FCA, and crash notification suitable for retrofit prototype deployment.
- A modular architecture separating time-critical warnings from event-driven IoT communication.
- Prototype implementation details, testing procedure, and cost summary to demonstrate feasibility.

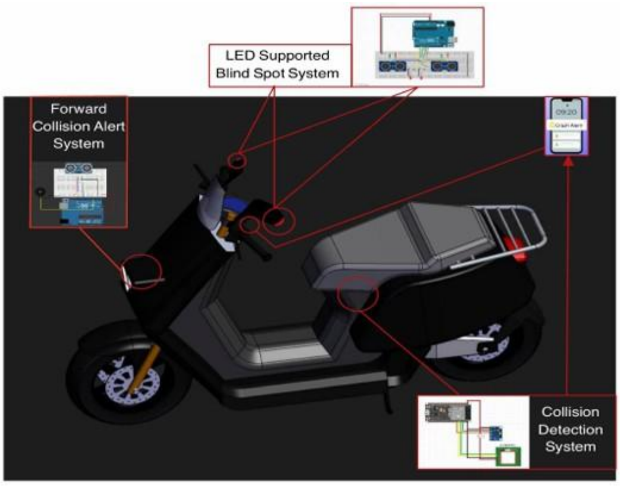

Fig. 1. Overall system architecture / overview of final design.

2. Related Work

Rider-assistance features for motorcycles commonly target either collision avoidance or post-crash notification. Blind-spot monitoring approaches use rear sensing to warn the rider of vehicles in adjacent areas. Forward-collision warning aims to detect obstacles ahead and issue timely alerts. Crash detection systems employ inertial sensing to detect abnormal motion and trigger emergency notification with location reporting.

While advanced perception solutions can improve accuracy, they often increase cost and integration complexity. This paper focuses on affordable ultrasonic sensing for proximity alerts and IMU+GPS for crash detection and reporting, achieving a practical system suitable for a low-cost prototype.

3. System Overview and Architecture

Fig. 1 presents the overall system architecture. The design is partitioned into:

1) **Pre-crash warning block:** an Arduino-class controller processes ultrasonic measurements and generates imme- diate rider feedback using LEDs (left/right) and a buzzer.
2) **Post-crash reporting block:** an ESP32 processes IMU measurements for crash detection. Once triggered, it acquires GPS coordinates and sends alerts to an IoT dashboard and email contact.

This separation improves reliability: proximity alerts run continuously and locally for fast response, while IoT com- munication is activated only when an accident is detected, reducing unnecessary network traffic and power consumption.

4. Hardware Design and Placement

A. Hardware Components

Table 1 summarizes the key hardware blocks used in the prototype.

Table 1 Hardware Blocks in the Proposed Prototype

Block	Role in System
Ultrasonic sensors	Distance measurement for blind-spot zones (rear) and collision zone (front)
Arduino-class MCU	Fast sampling + threshold decisions; drives LEDs and buzzer
ESP32 (Wi-Fi)	Crash-event processing + IoT communication
MPU6050 IMU	Latitude/longitude acquisition for alert message
LEDs + buzzer	Rider warnings: left/right LEDs, audible buzzer

Fig. 2. Sensor placement concept for blind-spot monitoring and forward- collision alert.

B. Sensor Placement

The rear sensors monitor the left/right blind-spot zones, while the front sensor monitors the direction of travel for collision risk. Fig. 2 shows the placement concept used in implementation.

5. Methods and Decision Logi

A. Ultrasonic Distance Estimation

Ultrasonic distance is obtained using time-of-flight (ToF) echo measurement. The estimated distance d is:

$$d = \frac{v \cdot t}{2}, \tag{1}$$

where v is the speed of sound and t is round-trip echo time.

B. Decision Thresholds

In the prototype, the warning and crash-event decisions are implemented using tunable thresholds. Table 2 summarizes the logic.

C. System Operation Algorithm

Algorithm 1 summarizes the continuous operation. Pre-crash sensing runs continuously; crash reporting is event-driven.

Table 2 Prototype Decision Logic (Tunable Thresholds)

Function	Decision Rule (Prototype)
Blind-spot alert	If rear-left or rear-right distance < dBSM, turn ON corresponding LED
Forward alert	If front distance < dFCA, activate buzzer warning
Crash detection	If IMU indicates abnormal impact/tilt pattern beyond preset threshold, trigger crash event
Notification	On crash event: acquire GPS coordinates and send dashboard + email alert

Algorithm 1 System Operation (Simplified)

```
Loop continuously:
Read rear-left, rear-right, and front ultrasonic distances
if d_left < d_BSM then
        Turn ON left LED
else
        Turn OFF left LED
end if
if d_right < d_BSM then
        Turn ON right LED
else
        Turn OFF right LED
end if
if d_front < d_FCA then
        Activate buzzer
else
        Deactivate buzzer
end if
Read IMU (acceleration, angular rate / tilt estimate)
if Crash threshold satisfied then
        Acquire GPS coordinates
        Send IoT dashboard notification
        Send email alert with coordinates
end if
```

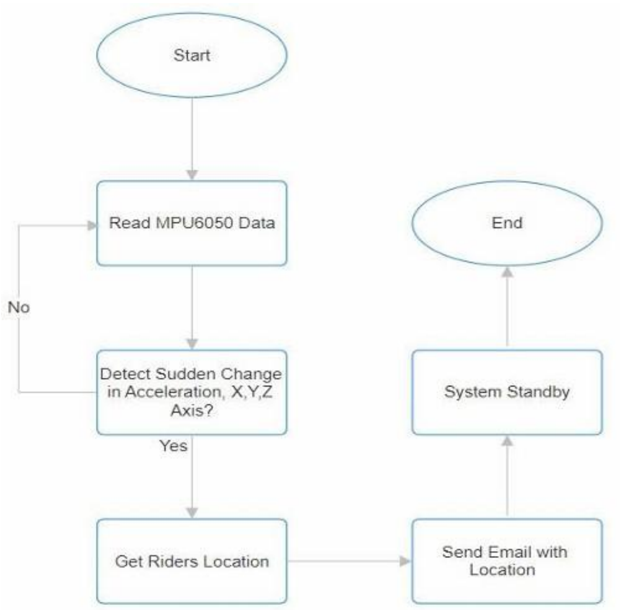

Fig. 3. Crash detection and notification flowchart used by the ESP32 block.

6. Prototype Implementation

A. Physical Prototype

A functional prototype was assembled with practical enclosure and mounting considerations for the sensors and electronics. Fig. 4 shows the finalized prototype configuration used during testing.

B. *Cost Summary*

Table 3 provides the cost summary reported for prototype- level implementation.

Fig. 4. Overview of the finalized prototype hardware implementation.

7. Experimental Setup and Results

A. *Pre-crash Warning Tests*

The BSM and FCA functions were tested by placing obsta- cles within the sensing zones and observing warning outputs:

- **Blind-spot:** an obstacle positioned in the left/right side zone triggered the corresponding LED.
- **Forward collision:** an obstacle positioned in front within the risk threshold activated the buzzer.

Across repeated trials, the prototype consistently responded when the obstacle crossed the threshold boundary, demon- strating stable warning behavior for close-range proximity conditions.

B. *Crash Detection and Notification Tests*

Crash-event behavior was evaluated through controlled im- pact/orientation change scenarios. When the crash condition was triggered, the system generated:

- an IoT dashboard alert indicating the crash event, and
- an email notification including the event information and GPS location.

Table 3 Cost Summary (Prototype-Level Bill of Materials)

Item	Cost (RM)
Total prototype cost (including model motorcycle)	331.19
Total cost (excluding model motorcycle)	233.19
Estimated with misc. additions (wires/box/shipping)	290–295

Blynk

Fig. 5. Example crash alert output (IoT dashboard and email notification).

C. *Discussion*

The prototype demonstrates that combining pre-crash warn- ings and post-crash reporting is achievable using low-cost sensing and modular microcontroller design. The separation of warning logic (local, continuous) and reporting (event-driven, IoT) improves responsiveness and avoids unnecessary commu- nication overhead. The cost summary indicates feasibility for low-cost development and further iteration.

D. *Limitations*

Ultrasonic sensors are sensitive to mounting angle, reflective surfaces, and environmental conditions. Wider on-road testing at realistic speeds is needed to evaluate performance in com- plex traffic. Crash thresholds also require calibration to reduce false triggers while maintaining reliable event detection.

8. Conclusion and Future Work

This paper presented an integrated IoT-enabled motorcycle safety prototype combining blind-spot monitoring, forward- collision alerts, and crash detection with GPS-based emer- gency notification. Controlled testing confirmed correct prox- imity warnings and successful crash-event reporting via dash- board and email. Future work will focus on extended on-road evaluation, improved sensor robustness, adaptive thresholds based on speed context, and compact integration with opti- mized power management.

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