

A Review Based on: Two Wheeler Crash Detection and Fall Analysis System

Dr. K Senthil Babu¹, Sakshi M², Pavithra P³, Ranjitha S⁴, Hruthwik H M⁵ ¹Professor, Electronics and Communication Engineering, K. S. School of Engineering and Management

²Student, Electronics and Communication Engineering, K. S. School of Engineering and Management

³Student, Electronics and Communication Engineering, K. S. School of Engineering and Management

⁴Student, Electronics and Communication Engineering, K. S. School of Engineering and Management

⁵Student, Electronics and Communication Engineering, K. S. School of Engineering and Management

Abstract—Two-wheeler accidents remain a major public safety challenge in many countries. Sensor based detection systems primarily using inertial measurement units (IMUs), GPS, and cellular links promise rapid detection and automated emergency notification to reduce the time to aid. This survey synthesizes recent academic and applied work on two wheeler crash and fall detection, focusing on sensing modalities, detection algorithms, communication pipelines, and system level design choices. We analyze threshold based IMU methods, machine learning classifiers, hybrid helmet/vehicle architectures, and trajectory prediction approaches. Key limitations include false positives from road roughness, dependence on GNSS/cellular coverage, limited field validation, and energy/size constraints for embedded deployment, cooperative V2X alerting, and standardized datasets for benchmarking. The paper concludes with recommendations for practical deployment and societal impact.

Index Terms—Two wheeler safety, crash detection, IMU, MPU6050, GPS, GSM, IoT, fall detection, trajectory prediction, emergency alerting.

I. INTRODUCTION

Two wheelers account for a disproportionate share of road fatalities in many regions. Rapid detection and notification of crashes can materially reduce mortality by shortening the time to medical assistance. Sensor-based systems combining IMUs (accelerometer + gyroscope), GPS/GNSS, and cellular or IoT links are the dominant approach in recent literature and prototypes. This survey consolidates findings from recent conference papers, technical reports, and project presentations to provide a coherent view of the state of the art, practical trade offs, and open research problems.

II. MOTIVATION AND SCOPE

Two-wheeler riders lack the passive protection of enclosed vehicles; hence, automated detection and rapid alerting are critical.

This survey focuses on:

- 1) **Sensing and detection:** IMU based thresholds, multi-sensor fusion, and ML based classifiers.

- 2) **Communication and alerting:** GPS/GSM/IoT pipelines, false-alert cancellation, and nearby user notification.
- 3) **System integration:** Helmet vs. vehicle mounted sensors, ignition interlocks, and engine cutoff concepts.
- 4) **Evaluation:** Accuracy, latency, and field validation reported in the literature.

The reviewed studies show that IoT-based accident detection systems using ESP32, GPS, GSM, MPU6050, FSR sensors, and machine learning achieve high detection accuracy (95–99.9%) with rapid response times. However, challenges remain, including internet dependency, sensor placement, environmental sensitivity, and the need for extensive real-world validation to improve reliability and scalability.

III. BACKGROUND

Sensor based accident detection for two wheelers has matured into several recurring design patterns: IMU thresholding, short confirmation windows to cancel false alarms, GPS tagged SOS messages, and helmet-integrated systems that add physiological or alcohol sensing. Representative projects and studies include IMU+GPS prototypes with cancel timers [2], smart helmets with alcohol and helmet wear checks, FSR-based impact sensing [7], and trajectory prediction risk assessment for vehicle-ETW interactions [8]. From project documentation, “Inertial Measurement Unit (IMU) Based Detection” is the core proposed idea for two-wheeler crash detection and fall analysis. The literature shows consistent use of MPU-6050 (accelerometer + gyroscope) as a low-cost IMU, Neo-6M or similar GNSS modules for localization, and SIM800/SIM900 GSM modules for SMS/call-based alerting [1], [2], [10].

A. Key Themes from Reviewed Works

IMU-centric detection: Most systems use acceleration magnitude, tilt angle, and angular velocity thresholds to detect falls or crashes.

False alert mitigation: Short confirmation windows (5–20 s) and user-cancel mechanisms are common to reduce false positives.

Multimodal sensing: Alcohol sensors (MQ-3), helmet-wear IR sensors, and pulse/SpO2 sensors are integrated in some helmet systems to add context and prevention features. Communication: GSM/SMS remains the most widely used fallback for emergency alerts due to ubiquity; IoT/cloud pipelines and smart phone apps are used where connectivity allows.

Trajectory and vision methods: For vehicle ETW interactions, trajectory prediction and probabilistic risk mapping provide early warnings in mixed traffic.

Vision and Trajectory based Risk Assessment Principle: Use camera-based detection and trajectory prediction (LSTM/Transformer or lightweight TP-tiny) to estimate collision probability and TTC (time-to-collision) for proactive warnings [8], [11].

Advantages: Early risk assessment in mixed traffic, useful for infrastructure-side monitoring.

Limitations: Occlusion, lighting sensitivity, high compute needs, and privacy concerns.

IV. EXISTING METHODOLOGIES

We classify existing approaches into four broad categories: (A) Threshold-based IMU detection, (B) Machine-learning classifiers on IMU features, (C) Hybrid helmet-vehicle systems with additional sensors, and (D) Vision/trajectory based risk assessment.

A. Threshold-based IMU Detection

Principle: Compute acceleration magnitude

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2}, \quad (1)$$

tilt angle from accelerometer/gyro fusion, and trigger when values exceed pre-set thresholds for a sustained interval. Typical thresholds: tilt angle $> 45^\circ$, acceleration spike $> 0.7g$ or higher depending on calibration.

Advantages: Simple, low-power, easy to implement on microcontrollers (ESP32/Arduino).

Limitations: Sensitive to road roughness, potholes, and aggressive maneuvers; requires careful tuning and per vehicle calibration.

B. Machine-Learning Classifiers on IMU Features

Principle: Extract time-domain and frequency-domain features from IMU streams (e.g., mean, variance, spectral energy, jerk) and classify events using Random Forest, SVM, or lightweight neural networks. Prajapati et al. reported high fall detection accuracy using Random Forest on accelerometer + gyro features.

Advantages: Better discrimination between crash and non-crash events; adaptable via retraining.

Limitations: Requires labeled datasets, may be heavier computationally, and risks overfitting to controlled tests.

C. Hybrid Helmet-Vehicle Systems

Principle: Combine helmet-mounted sensors (IMU, FSR, pulse, alcohol) with vehicle-mounted IMU/GPS and smart-phone apps. Systems implement ignition interlocks, engine cutoff via solenoid/relay, and multi-stage alert confirmation.

Advantages: Richer context (helmet-wear, rider vitals), prevention (ignition lock), and redundancy.

Limitations: Increased cost, complexity, and user acceptance challenges.

D. Vision/Trajectory Based Risk Assessment

Trajectory prediction and probabilistic risk assessment can be used for vehicle ETW interactions. Camera-based detection and trajectory prediction methods can estimate collision probability and time-to-collision for proactive warnings [8], [11].

Advantages: Early risk assessment in mixed traffic and usefulness for infrastructure-side monitoring.

Limitations: Occlusion, lighting sensitivity, high compute needs, and privacy concerns.

V. CHALLENGES AND RESEARCH GAPS

From the surveyed literature, we identify the following open problems.

A. Robust Multimodal Fusion

Combining IMU, GNSS, FSR, physiological sensors, and vision in a principled probabilistic framework remains an open challenge. Fusion must be robust to missing modalities (e.g., GNSS outage) and sensor noise.

B. Adaptive and Personalized Thresholding

Static thresholds do not generalize across riders, vehicles, and road conditions. Adaptive thresholds or on-device personalization (calibration during normal riding) can reduce false alarms.

C. Lightweight On-device Learning

Most ML approaches assume cloud compute. There is a need for compact models (tinyML) that can run on ESP32 class hardware for continuous inference and occasional on-device adaptation.

D. Standardized Datasets and Benchmarks

The field lacks large, diverse, labeled datasets for two-wheeler crash/fall events across varied road conditions. Public benchmarks would accelerate reproducible research.

E. Privacy-preserving Alerting and Data Sharing

Designs must balance rapid emergency notification with rider privacy. Techniques such as selective disclosure, encrypted alerts, and consented data sharing are needed.

F. Cooperative and Infrastructure-assisted Alerting

Integration with roadside units, traffic cameras, and V2X networks can improve detection and response, but standards and interoperability are immature for two-wheeler use cases.

VI. PROPOSED FUTURE DIRECTIONS

We propose a set of research and engineering directions to address the gaps.

A. Probabilistic Multimodal Fusion Framework

Develop a Bayesian or particle-filter-based fusion engine that ingests IMU, GNSS, FSR, and optional vision cues to compute a collision probability score. Use TTC and distance metrics where trajectory data is available [8].

B. TinyML for On-device Classification

Design compact neural or tree-based models optimized for microcontrollers (quantized, pruned) to classify crash vs. non-crash events with sub-100 ms inference latency.

C. Adaptive Calibration and Continual Learning

Implement lightweight online calibration: collect normal-ride statistics and adapt thresholds or classifier parameters to rider/vehicle profiles while preserving privacy.

D. Hybrid Alerting with Local Redundancy

Combine GSM/SMS with BLE based local broadcast to nearby app users and opportunistic upload to cloud when connectivity returns. Buffering and store-and-forward mechanisms (as in [9]) are essential.

E. Standardized Testbeds and Datasets

Create a shared dataset of instrumented two-wheeler rides with annotated events (normal ride, near-miss, skid, crash) across varied surfaces and speeds. Define evaluation metrics: detection accuracy, false alarm rate, latency, and localization error.

F. Privacy and Security by Design

Adopt end-to-end encryption for alerts, minimal disclosure (only coordinates and emergency token), and user-controlled contact lists. Consider decentralized alerting protocols to avoid single-point failures.

VII. ADVANTAGES AND LIMITATIONS OF CURRENT APPROACHES

A. Advantages

Low-cost hardware availability: MPU6050, Neo-6M, and SIM800/900 modules enable affordable prototypes.

Rapid prototyping and integration: ESP32/Arduino ecosystems accelerate development and smart phone integration.

Proven benefit of automated alerts: Field and prototype studies show that automated alerts can reduce time-to-aid.

B. Limitations

- 1) **False positives/negatives:** Road roughness, potholes, and aggressive maneuvers cause false triggers; conversely, some crash profiles may not exceed thresholds.
- 2) **Connectivity and localization gaps:** GNSS and cellular coverage limitations reduce reliability in certain environments.
- 3) **Limited large-scale validation:** Most works report controlled tests or small pilots; generalization to diverse road conditions is under-explored.
- 4) **Privacy and security:** Transmitting location and health data raises privacy concerns; secure, consented alerting is necessary.

VIII. CONCLUSIONS

Sensor-based two-wheeler crash detection systems have emerged as effective and cost-efficient solutions for improving rider safety. By integrating IMU sensors, GPS, GSM, and machine learning techniques, these systems enable accurate accident detection and rapid emergency alerts. Although challenges such as false alarms, network dependency, and real-world validation remain, advances in sensor fusion and edge intelligence can further improve system performance. Overall, the proposed system demonstrates significant potential to enhance emergency response, reduce accident-related fatalities, and contribute to safer transportation.

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