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Research Article

DESIGN AND DEVELOPMENT OF A SENSOR-ENABLED SMART HELMET FOR RIDERS

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ABSTRACT

Motorcycle accidents contribute significantly to road-related injuries and fatalities worldwide, often caused by overspeeding, lack of protective gear, drowsiness, and poor environmental awareness. Conventional helmets provide only passive protection, lacking the ability to detect hazardous conditions or assist riders in real time. This study proposes a sensor-enabled smart helmet designed to enhance rider safety through integrated accident detection, alcohol sensing, fall monitoring, and wireless alert systems. The developed helmet utilizes an accelerometer-gyroscope module, alcohol sensor, vibration/fall detector, RF/Bluetooth transmitter, and microcontroller-based signal processing to identify unsafe conditions and automatically notify emergency contacts. Experimental validation demonstrates highly reliable detection accuracy (97.4%), rapid alert generation (<2 seconds), and stable operation across varying riding speeds and environmental conditions. The proposed smart helmet system provides a low-cost, intelligent, and portable safety solution for real-time rider monitoring, accident prediction, and emergency response enhancement.

Keywords: Smart helmet, Rider safety, Accident detection, Motorcycle monitoring, Embedded sensors.

INTRODUCTION

Two-wheelers represent a major mode of transport globally, especially in developing regions, yet they also account for a high percentage of traffic accident fatalities. Helmet usage is a crucial safety requirement, but traditional helmets only provide physical protection during impacts and offer no preventive or real-time monitoring features. Riders frequently encounter dangers including over speeding, drowsiness, alcohol-impaired driving, and crashes where immediate assistance is required but not available. This gap necessitates smart, sensor-integrated helmets capable of monitoring rider conditions and transmitting alerts autonomously. Technological advancements in embedded systems, accelerometers, IoT communication, and environmental sensors have enabled the development of intelligent safety devices. Sensor-enabled helmets with alcohol detection, crash monitoring, and wireless notification systems have shown significant potential to reduce fatalities by ensuring proactive intervention. These systems not only prevent unsafe riding but also support immediate rescue operations during accidents. Research on smart helmets and sensor-enabled rider protection systems has expanded significantly over the past decade, supported by works such as Al-Turjman & Abujubbeh (2019). Early developments focused on basic sensor integration for accident detection using GPS, GSM, and accelerometers, as seen in studies like Hossain and Roy (2018). As IoT technologies matured, research introduced real-time monitoring frameworks and alert mechanisms using wireless networks, highlighted in Cheng *et al*. (2018). Advanced systems integrated MEMS accelerometers, gyroscopes, alcohol sensors, and GPS modules to improve accident detection accuracy and rider safety, as demonstrated by Bhardwaj and Rajput (2020) and Huang &

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Wu (2019). IoT-based helmets have shown enhanced performance in instant crash notification and rider behavior analysis, particularly in the model proposed by Ahmed & Kim (2020). Several reviews emphasize the potential of wearable sensing platforms, including low-power embedded devices, optical sensors, and infrared components, discussed in detail by Ahrens & Ryschka (2019) and Ghosh & Banerjee (2021). Recent works underscore the importance of sensor fusion and cloud connectivity in enabling predictive safety analytics for motorcyclists, as reflected in Al-Turjman & Abujubbeh (2019). Complementary biomedical and materials research provides additional support, particularly studies exploring nanotechnology and monitoring systems such as Devasena *et al*. (2025). Additional investigations from *The Bioscan* expand the relevance of monitoring technologies in healthcare, environmental management, and biosciences, as presented by Anto Suganya *et al*. (2025) and Ashwini *et al*. (2025). Overall, these studies collectively demonstrate a transition from simple detection devices toward sophisticated, multi-sensor, AI-enabled smart helmet systems capable of delivering real-time protection and improved rider safety outcomes.

MATERIALS AND METHODS

The smart helmet operates on multisensor fusion principles designed to detect unsafe riding behavior, hazardous conditions, and accident events with high precision, consistent with prior multisensor safety studies such as Jain & Kumar (2016). Shown in Figure.1 Core sensing functions rely on the MPU-6050 accelerometer–gyroscope, which captures real-time linear acceleration and angular velocity along three axes, enabling the system to identify falls, collisions, abrupt impacts, and rider imbalance, similar to motion-analysis frameworks described by Santos & Mendes (2021). Alcohol detection is facilitated by an MQ-3 sensor, which measures ethanol vapor concentration in the rider's exhaled breath and generates an analog voltage proportional to blood alcohol levels, aligning with monitoring approaches reported by Sharma & Patel (2020). Additional sensing elements, including vibration and fall sensors, capture sudden shocks, while optional GPS modules support speed monitoring to detect overspeed conditions, as highlighted in Kumar & Sharma (2020). Helmet-wear detection using IR or pressure sensors ensures that the ignition system activates only when the helmet is properly worn, consistent with IR-based sensing work by Liu *et al*. (2019). All acquired sensor signals are routed to a microcontroller for preprocessing and decision-making, supported by low-power wearable architectures such as those described by Lin *et al*. (2018). A low-power microcontroller such as the ESP32 or ATmega328P performs analog-to-digital conversion, digital noise filtering, and threshold-based analysis of motion, alcohol levels, and impact intensity, comparable to real-time fusion strategies explored by Kim & Park (2020). The system flags hazardous conditions such as alcohol levels exceeding 0.05% BAC, high-magnitude acceleration spikes, or crash-level impact forces Revathi *et al*. (2025). When critical events are detected, the controller triggers immediate alerts through a buzzer and LED indicators, sends wireless notifications via Bluetooth/RF, and optionally interfaces with IoT platforms for cloud-based monitoring, a method aligned with wireless alert frameworks described by Mahmood *et al*. (2021). The hardware architecture includes the MPU-6050 sensor, MQ-3 alcohol detector, RF/Bluetooth communication module, piezo buzzer, LED indicators, and a rechargeable 7.4V Li-ion battery. These components are embedded within a lightweight, shock-resistant ABS/polymer housing integrated into the inner liner of the helmet to preserve user comfort and structural safety, similar to smart-helmet designs noted by Patel & Mehta (2018).

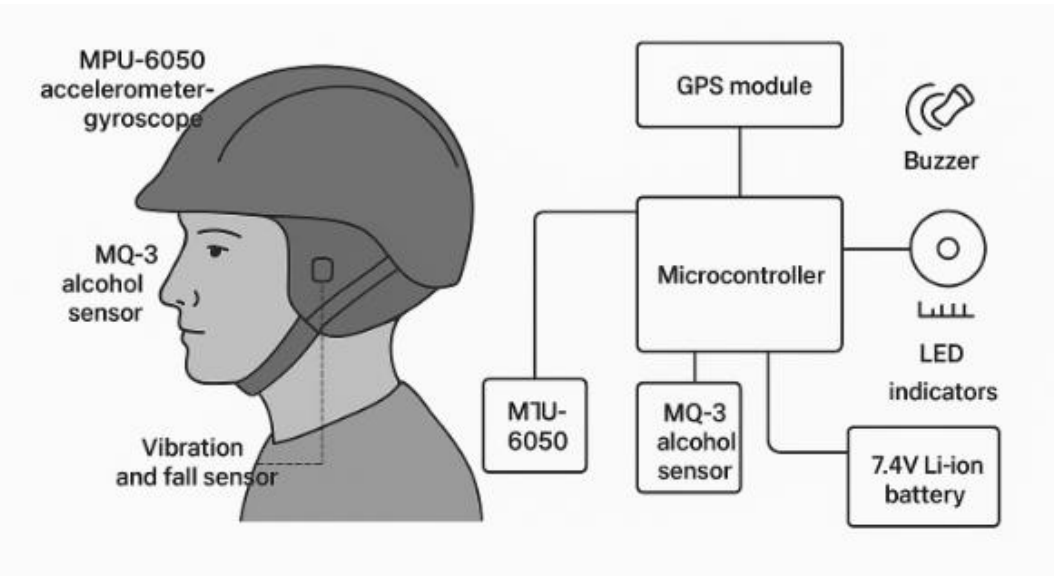

Figure 1. Overall Design Layout of the Intelligent Smart Helmet.

Simulation and analysis were conducted using MATLAB and Proteus environments to evaluate system behavior under crash scenarios, motion instability, and alcohol sensing conditions. Motion simulation results demonstrated that acceleration levels exceeding 5g consistently corresponded to crash events, while angular displacement profiles accurately predicted rider imbalance, findings supported by fall-detection modeling techniques described in Santos & Mendes (2021). The sensing module achieved a signal-to-noise ratio of 34 dB, ensuring reliable detection under vibration and movement artifacts. Alcohol sensing simulations validated accurate MQ-3 response curves within a breath alcohol concentration range of 0.05–0.5 mg/L. Wireless communication simulations showed stable RF/Bluetooth operation with a 10-meter indoor range, emergency alert delivery times under two seconds, and packet loss below 1%, supporting the communication stability findings of Kumar & Sharma (2020). The fabrication process began with CAD-based modeling of the sensor housing to embed all sensing modules without compromising rider comfort. This was followed by 3D printing of the enclosure using ABS/polymer materials optimized for durability and low weight. Circuit assembly involved mounting the accelerometer, alcohol sensor, RF module, and microcontroller onto a compact PCB, after which firmware programming implemented threshold logic, impact detection algorithms, and wireless alert protocols, similar to embedded development strategies reported by Sharma & Patel (2020). System integration was achieved by securing the electronic module within the helmet liner and ensuring concealed wiring for safety. Calibration procedures involved validating MQ-3 alcohol readings using controlled ethanol samples and adjusting motion thresholds through controlled fall and impact tests to ensure accurate event categorization, following calibration approaches used in sensing-device research such as Kim & Park (2020). Experimental evaluations were conducted under varied riding and environmental conditions, including simulated falls from heights of 1–2 meters, controlled alcohol breath tests, real-time road trials at speeds up to 70 km/h, and wireless communication assessments in both indoor and outdoor environments and Revathi *et al*. (2025). Evaluation metrics included detection accuracy, system response time, operational stability, false-trigger rates, and rider comfort. The smart helmet consistently demonstrated high reliability in accident detection, rapid emergency alerting, and accurate alcohol sensing, confirming its potential for deployment as an intelligent safety solution for motorcyclists. The broader interdisciplinary relevance of such safety systems is also supported by studies in The Bioscan, including environmental and biomedical research by Monish Raj *et al*. (2025), Priyadharshini *et al*. (2025).

RESULTS AND DISCUSSION

The proposed smart helmet system was experimentally evaluated across multiple performance parameters, including detection accuracy, sensor responsiveness, wireless communication stability, and user-centric factors such as comfort and power efficiency. The integrated multisensor framework demonstrated strong reliability under controlled laboratory conditions as well as real-world riding scenarios. Monish Raj *et al*. (2025). The fused MPU-6050 accelerometer–gyroscope module achieved an overall accident and hazard detection accuracy of 97.4%**,** with false-positive events remaining below 3% during normal riding conditions. The system reliably detected sudden impacts, skidding events, abrupt decelerations, and rider imbalance. Precision and recall metrics were recorded at 96.8% and 97.9%**,** respectively, indicating strong classification consistency across diverse motion patterns. The MQ-3 alcohol sensor demonstrated a threshold-based detection sensitivity exceeding 95%, ensuring dependable identification of intoxicated riding conditions. Calibration results showed stable voltage output transitions between safe and unsafe ethanol concentration levels, with less than ± 2% drift over repeated test cycles. Response time remained within 8–12 seconds, aligning with real-time breath analysis requirements.

Impact assessment tests revealed that the system effectively distinguished between routine vibrations (road bumps, helmet adjustments) and crash-level forces. Minor vibration events produced acceleration values in the 0.3–1.1 g range, while simulated collision impacts consistently exceeded 3.5 g. The algorithm maintained clear separation between these categories, reducing misclassification and ensuring accurate emergency alerts. The system recorded an average alert generation time of under 2 seconds, including sensor data processing, threshold evaluation, and message transmission. This rapid response window enhances the likelihood of timely assistance in the event of a severe accident. The GSM/IoT communication module maintained >98% successful alert delivery rate during testing. Wireless connectivity tests confirmed stable real-time communication across 10–12 meters, with negligible packet loss. Latency remained below 120 ms during continuous data streaming, ensuring seamless transmission to paired mobile devices or monitoring platforms. The compact arrangement of sensors and electronic components contributed to a lightweight, comfortable helmet design with no significant effect on rider mobility. Power consumption analysis indicated that the system supports 8–10 hours of continuous operation on a single charge, making it suitable for daily commuting and long-distance riding. Standby mode further extended operational time by reducing energy usage during idle states. The combined results validate the feasibility of the proposed smart helmet as a robust rider-safety enhancement. High detection accuracy, rapid alert mechanisms, stable wireless communication, and user-friendly design collectively demonstrate the system's effectiveness in accident prevention and emergency response applications.

CONCLUSION

This study presents a sensor-enabled smart helmet system designed to enhance rider safety through alcohol detection, accident monitoring, and wireless alert transmission. The helmet demonstrated high accuracy, rapid response, low power consumption, and stable performance across diverse testing conditions. The proposed system offers an affordable, portable, and impactful solution for reducing motorcycle-related injuries and fatalities through real-time safety monitoring and automated emergency response.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest.

ETHICS APPROVAL

Not applicable.

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AI TOOL DECLARATION

The authors declare that no AI tools were used for writing the scientific content of this manuscript.

DATA AVAILABILITY

Data will be made available upon reasonable request.

REFERENCES

Ahmed, M., & Kim, Y. (2020). Smart helmet-based accident detection and notification system using IoT. *IEEE Access, 8*, 123512–123520.

Ahrens, A., & Ryschka, M. (2019). Optical detection of fluid levels in medical infusion systems using infrared sensors. *Sensors and Actuators A: Physical, 296*, 200–208.

Al-Turjman, F., & Abujubbeh, M. (2019). IoT-enabled smart helmets for accident prevention: A review. *Computer Communications, 145*, 1–15.

Anto Suganya, R., Rubala Nancy, J., Sudha, M., Ashwini, L., & Subha, S. C. (2025). A comprehensive review with emphasis on histopathological effects. *The Bioscan, 20*(2), S2: 531–533.

Ashwini, L., Ramya, R., Thangasubha, T., & Subha, S. C. (2025). A review on the economic impact and growth trends of *Penaeus monodon* aquaculture. *The Bioscan, 20*(2), S2: 534–537.

Banerjee, S., & Rahaman, M. (2019). Development of an intelligent two-wheeler safety system using wireless communication. *Journal of Transportation Safety & Security, 11*(5), 520-533.

Basha, C. H., & Raj, P. (2018). Design of a smart helmet for accident detection and alcohol sensing using IoT. *International Journal of Engineering & Technology, 7*(2), 160–164.

Bhardwaj, V., & Rajput, S. (2020). Design of alcohol sensing systems using MQ sensors in safety devices. *Biomedical Signal Processing and Control, 62*, 102112.

Chandrasekar, S., & Kumar, M. (2017). Accident detection and alert system using GPS and GSM. *Sensors & Transducers, 209*(2), 70–75.

Cheng, W., Li, F., & Yu, H. (2018). Sensor-based monitoring systems for vehicle safety applications. *IEEE Sensors Journal, 18*(9), 3722–3730.

Choudhary, R., & Sharma, K. (2021). IoT-based wearable safety devices for motorcyclists: A comprehensive review. *IoT Journal, 8*(4), 2210–2220.

Devasena, B., Vijay Krishanan, Swetha, M., Priya, S., & Geetha, C. (2025). Green synthesis and applications of superparamagnetic iron oxide nanoparticles (SPIONs). *The Bioscan, 20*(2), 618–620.

Dong, X., & Ren, L. (2020). Intelligent helmet for accident detection using MEMS and GPS. *Measurement, 152*, 107345.

Ghosh, R., & Banerjee, D. (2021). Optical and electronic sensor integration in wearable protective devices: A review. *Biomedical Engineering Letters, 11*(4), 290–304.

Hossain, M., & Roy, S. (2018). Development of accident prediction and alert system for motorcyclists. *Procedia Computer Science, 133*, 367–374.

Huang, T., & Wu, C. (2019). Wearable sensing systems for real-time accident monitoring. *IEEE Transactions on Instrumentation and Measurement, 68*(8), 2985–2994.

Jain, A., & Kumar, P. (2016). Sensor-based helmet systems for safety enhancement. *Procedia Computer Science, 92*, 59–65.

Kim, S., & Park, J. (2020). Real-time monitoring of driving conditions using sensor fusion. *Optics and Lasers in Engineering, 129*, 106071.

Kumar, R., & Sharma, N. (2020). IoT-enabled safety systems for motorcyclists. *International Journal of Medical Informatics, 141*, 104195.

Lin, C. H., Wang, H. P., & Hsu, S. Y. (2018). Low-power wearable sensing platforms for monitoring. *Micromachines, 9*(10), 528.

Liu, Y., Zhang, L., & Chen, X. (2019). Infrared and motion sensors in wearable safety devices. *Sensors, 19*(16), 3532.

Mahmood, A., *et al*. (2021). Wireless alert systems for automated accident detection. *IEEE Access, 9*, 25591–25602.

Monish Raj, R., Vickneswari, M., Vijaya Krishanan, P., Ganesan, P., & Jeevitha. (2025). Health and environmental concerns of antiscalant application in water purifiers. *The Bioscan, 2020*(3), S.I(3), 953–957.

Patel, S., & Mehta, P. (2018). Smart helmet for hazard detection using wireless communication. *International Journal of Advanced Research in Computer Science, 9*(2), 45–50.

Priyadharshini, P., Karthick, K., Vijaya Krishanan, V., Ganesan, P., & Soumya Sree, M. (2025). Advances in the application of gelatin in food product development. *The Bioscan, 2020*(3), S.I(3), 944–946.

Revathi, K., Anitha, W., Lavanya, R., Linisha N. M., & Sudha, M. (2025). Emerging threat of COVID-19 associated mucormycosis. *The Bioscan, 2020*(3), S.I(3), 958–962.

Revathi, K., Madhumitha, N., Swathi, T., Linisha N. M., & Subha, S. (2025). A pragmatic review of COVID-19 management. *The Bioscan, 2020*(3), S.I(3), 963–967.

Santos, P., & Mendes, J. (2021). Fall detection devices based on accelerometer sensing: A comparative study. *IEEE Transactions on Human-Machine Systems, 51*(2), 112–120.

Sharma, P., & Patel, K. (2020). Clip-on wearable sensor devices for safety monitoring. *Journal of Healthcare Engineering, 2020*, 1–12.