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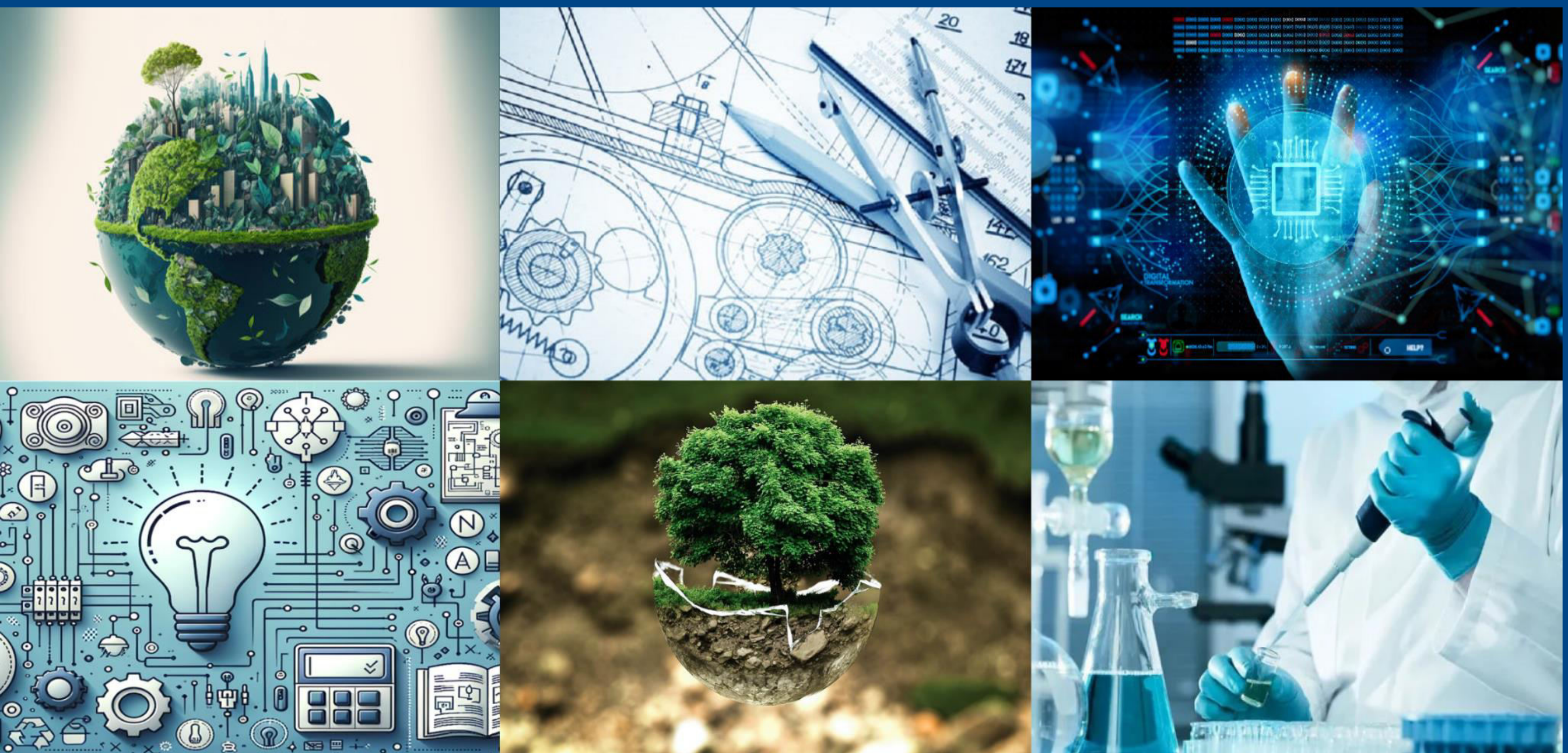

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www.ijmrset.com ijmrset@gmail.com +91 6381 907 438 +91 63819 07438

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AI-Based Multi-State Driver Monitoring System for Motor Vehicle Safety Enhancement

Mariel M. Azarcon[1], Brian L. Cubero[2], Rea M. Maratas[3], ENGR. CHERYL O. TAYO, MIT, MSCpE[4], ENGR. DIONE S. DUERO, MSCpE[5], ENGR. FRANKLIN M. GANANCIAS, DIT[6], ENGR. NELYNE LOURDES Y. PLAZA, PCpE, PhD[7]

Undergraduate Student, Department of Computer Studies, North Eastern Mindanao State University - Cantilan Campus, Cantilan, Surigao del Sur, Philippines[1]

Undergraduate Student, Department of Computer Studies, North Eastern Mindanao State University - Cantilan Campus, Cantilan, Surigao del Sur, Philippines[2]

Undergraduate Student, Department of Computer Studies, North Eastern Mindanao State University - Cantilan Campus, Cantilan, Surigao del Sur, Philippines[3]

Associate Professor IV, Department of Computer Studies, North Eastern Mindanao State University - Cantilan Campus, Cantilan, Surigao del Sur, Philippines[4]

Instructor I, Department of Computer Studies, North Eastern Mindanao State University - Cantilan Campus, Cantilan, Surigao del Sur, Philippines[5]

Associate Professor III, Department of Computer Studies, North Eastern Mindanao State University - Cantilan Campus, Cantilan, Surigao del Sur, Philippines[6]

Professor VI, Department of Computer Studies, North Eastern Mindanao State University - Cantilan Campus, Cantilan, Surigao del Sur, Philippines[7]

Email: azarconmarielmiranda@email.com , briancubero2@gmail.com, maratasream@email.com, cotayo@nemsu.edu.ph

ABSTRACT: This study developed an AI-based smart helmet system designed to improve motorcycle safety by detecting rider impairment, such as drowsiness and alcohol intoxication, in real time. Using a developmental-descriptive research design and Agile methodology, the system integrated MQ-3 alcohol sensors, infrared sensors, Arduino microcontrollers, a buzzer alert, and an engine interlock mechanism. A rule-based embedded AI algorithm analyzed sensor data to classify rider conditions and trigger safety responses. Testing results showed accurate real-time monitoring, reliable detection, and effective alert activation. The system demonstrated high usability, comfort, and reliability, proving that embedded AI and multi-sensor integration can support proactive accident prevention and enhance motorcycle safety.

KEYWORDS: Smart Helmet, Embedded Artificial Intelligence, Drowsiness Detection, Alcohol Detection, Engine Interlock Control

I. INTRODUCTION

Ensuring transportation safety remains a major challenge due to the negative effects of human impairment on driving performance, particularly among motorcycle riders. Improving motorcycle safety through real-time rider monitoring and automated preventive measures has become increasingly important in reducing accident risks. The AI-based multi-state driver monitoring system integrated into a smart helmet is designed to detect unsafe rider conditions, such as drowsiness and alcohol intoxication, using embedded sensors and intelligent decision-processing mechanisms. Since these impairment conditions are among the leading causes of motorcycle accidents, the system continuously monitors the rider's condition in real time. It automatically activates safety responses, including warning alerts and engine interlock control. By integrating sensor-based detection with embedded artificial intelligence, the study aims to prevent unsafe riding situations and enhance overall road safety.

Recent research highlights the growing importance of intelligent helmet systems and embedded driver-monitoring technologies in improving transportation safety. Lee et al. (2022) [8] reported that smart helmet platforms integrating multiple sensors enhance real-time detection of unsafe riding conditions and provide early warnings that reduce accident risk. Fu et al. (2024) [4] emphasized the role of continuous monitoring and alert mechanisms in mitigating fatigue-related accidents. Kumar et al. (2023) [7] demonstrated that embedded alcohol detection, combined with ignition control, can effectively reduce impaired-driving incidents. Furthermore, Li et al. (2022) [9] and Zhang et al. (2023) [19] showed that sensor-based monitoring approaches provide practical alternatives to computationally intensive vision systems, enabling wearable deployment in resource-constrained environments.

Despite recent advancements, many existing systems focus on a single impairment condition or rely heavily on camera-based artificial intelligence, thereby increasing system complexity, cost, and power consumption. Few studies have successfully integrated drowsiness detection, alcohol monitoring, helmet validation, and operational enforcement into a single wearable platform. Moreover, most driver monitoring systems emphasize detection rather than preventive control, limiting their effectiveness in real-world motorcycle safety applications.

To address these gaps, this study aims to develop a smart helmet system that integrates multi-sensor monitoring, rule-based embedded artificial intelligence, and an engine interlock mechanism. The proposed system enables real-time detection of rider impairment and enforces preventive safety measures by activating alerts and restricting vehicle operation under unsafe conditions, thereby improving overall motorcycle safety.

The purpose of this study is to design, develop, and evaluate a wearable smart helmet capable of continuously monitoring rider condition and preventing unsafe motorcycle operation. By integrating alcohol detection, eye-closure monitoring, wireless communication, and ignition control within a low-cost embedded architecture, the study advances intelligent transportation safety technologies. It supports the shift from passive protection to proactive accident prevention.

II. LITERATURE SURVEY

Foreign Related Literature (Hardware Systems)

The continuous advancement of intelligent transportation technologies has encouraged researchers to develop hardware-integrated smart helmet systems that improve motorcycle rider safety and reduce accident risks. In this regard, Choi et al. (2022) [2] explained that smart helmets integrate alcohol sensors, fatigue monitoring systems, and wireless communication technologies to support continuous rider monitoring and transportation safety applications. Their findings emphasized that embedded wearable systems provide practical and reliable monitoring performance.

The integration of alcohol detection and fatigue monitoring mechanisms into wearable transportation systems also became an important area of development. Islam et al. (2023) [6] developed a power-efficient smart helmet designed for drowsiness detection using embedded sensors and microcontroller-based processing systems. Experimental findings revealed that embedded hardware systems effectively support fatigue monitoring and improve transportation safety reliability.

Local Related Literature (Hardware Systems)

In response to the increasing need to improve motorcycle rider safety in the Philippines, local researchers have developed smart helmet systems capable of monitoring unsafe riding conditions through embedded technologies. Santos et al. (2023) [15] developed a smart helmet system integrating alcohol sensors, embedded microcontrollers, and communication modules into a wearable platform. Their methodology focused on detecting unsafe rider behavior and activating warning alerts during dangerous situations.

The use of multiple sensing technologies also became an important focus in local smart helmet development. Villanueva and Perez (2022) [18] designed a microcontroller-based helmet monitoring system equipped with multiple sensors capable of detecting improper helmet usage and abnormal rider movement. Findings from the study revealed that integrating multiple hardware components enhances monitoring capability and improves detection accuracy.

Foreign Related Literature (Software Systems)

Artificial intelligence and embedded software technologies have become essential components in modern rider monitoring systems because of their capability to analyze behavioral patterns and automate safety responses in real time. Hashemi et al. (2022) [5] developed a real-time drowsiness detection system using convolutional neural network algorithms to analyze eye-status behavior and fatigue conditions. The study demonstrated that software-based artificial intelligence improves monitoring reliability and supports real-time fatigue detection within wearable transportation safety systems.

Researchers also explored hybrid monitoring approaches capable of combining multiple detection techniques within a single intelligent platform. Nasri et al. (2022) [11] conducted a comprehensive review of software-based drowsiness detection systems involving facial recognition, physiological signal analysis, and behavioral monitoring technologies. Their findings emphasized that hybrid software systems improve monitoring reliability and provide more accurate rider condition analysis compared to single-method detection approaches.

Local Related Literature (Software Systems)

The continuous advancement of rider monitoring technologies in the Philippines has encouraged local researchers to improve embedded software systems for efficient real-time sensor data processing. Lopez et al. (2023) [10] developed an embedded monitoring system that utilizes microcontroller-based programming to process sensor inputs continuously in real time. Results from repeated testing and evaluation showed that real-time software processing significantly improves system responsiveness and operational efficiency.

Researchers also explored the use of automated decision-making algorithms to strengthen rider safety and improve detection accuracy. Navarro and Cruz (2022) [12] explored the use of rule-based algorithms in detecting unsafe rider conditions within embedded monitoring systems. Experimental results revealed that rule-based software processing improves detection accuracy, reduces false alarms, and enhances overall system reliability.

Foreign Related Studies

Efforts to improve drunk-driving prevention led researchers to integrate alcohol detection and automated alert mechanisms into wearable safety devices. Vanaja et al. (2023) [17] developed a smart helmet system designed for drunk-driving detection and automated alert generation using MQ-series alcohol sensors and embedded communication modules. The study demonstrated that embedded alcohol detection systems improve rider monitoring efficiency and support proactive accident prevention through automated safety enforcement.

The expansion of IoT technologies further strengthened the capability of wearable monitoring systems to support continuous rider supervision and real-time communication. Suryawanshi et al. (2023) [16] developed an IoT-enabled smart helmet integrating alcohol detection, drowsiness monitoring, and helmet verification technologies within a cloud-based communication platform. Findings from the study revealed that IoT integration significantly improves monitoring reliability, communication efficiency, and emergency response capability in wearable transportation safety applications.

Local Related Studies

In the Philippines, the growing concern over motorcycle-related accidents has led to increased research on smart helmet systems designed to enhance rider safety through real-time monitoring and automated response. Delos Santos et al. (2023) [3] developed a smart helmet capable of detecting alcohol levels and monitoring rider condition using embedded sensors and microcontrollers. Through prototype testing, the system demonstrated effective detection and immediate response, highlighting the potential of wearable safety devices in reducing accident risks.

To address delays in emergency response during accidents, Aquino and Ramos (2024) [1] developed a smart helmet equipped with accident detection and automated alert features. Results showed that the system successfully transmitted alerts in real time, emphasizing the importance of combining monitoring systems with emergency response capabilities to improve overall safety outcomes.

Synthesis of the Review

The reviewed literature and studies collectively demonstrate significant advances in intelligent rider monitoring systems through the integration of hardware, software, and embedded decision-making technologies. Foreign and local researchers consistently emphasized the importance of combining sensors, microcontrollers, wireless communication modules, and embedded algorithms to support real-time detection of unsafe riding conditions. The studies highlighted that continuous monitoring, automated alert systems, wireless communication, and rule-based processing improve system responsiveness, monitoring accuracy, and overall rider safety performance.

Despite these technological advancements, several limitations remain evident in existing systems. Many studies have focused only on single-condition monitoring, such as alcohol or drowsiness detection, without integrating multiple rider impairment factors into a unified platform. Some systems also relied on computationally intensive or expensive technologies that may not be practical for wearable, low-cost applications. These identified gaps support the development of the proposed AI-Based Multi-State Driver Monitoring System for Motor Vehicle Safety Enhancement. By integrating multiple sensors, embedded artificial intelligence, wireless communication, and an engine interlock mechanism within a wearable smart helmet, the proposed system provides a more practical, comprehensive, and efficient solution for real-time rider monitoring and proactive accident prevention.

III. METHODOLOGY

This study utilized a developmental-descriptive research design to address motorcycle accidents caused by rider drowsiness and alcohol intoxication through the development of an AI-based smart helmet monitoring system. The researchers used the Agile Development Model as the primary approach to allow continuous design, testing, and improvement of the system. The methodology focused on developing a wearable safety device capable of monitoring rider conditions in real time. The study also aimed to provide automated safety responses to prevent unsafe motorcycle operation. Through this approach, the researchers were able to systematically develop and evaluate the proposed system.

The methodology involved designing and integrating both hardware and software components required for the monitoring system. The hardware components included Arduino microcontrollers, MQ-3 alcohol sensors, infrared sensors, wireless communication modules, relay modules, and buzzer alerts. Meanwhile, the software was developed using Arduino IDE with a rule-based artificial intelligence algorithm capable of processing sensor data and classifying rider conditions. The system was programmed to detect unsafe conditions such as drowsiness, alcohol intoxication, and improper helmet usage in real time. This integration allowed the system to continuously monitor rider behavior and activate the appropriate safety response.

To rectify the problem of impaired riding, the system automatically activates warning alerts and engine interlock mechanisms whenever drowsiness or intoxication is detected. Testing and calibration procedures were conducted to evaluate sensor accuracy, response time, wireless communication stability, and overall system performance under controlled and simulated conditions. The developed prototype underwent hardware, software, and integration testing to ensure reliable operation during real-time monitoring. Evaluation of the system was also conducted in terms of functionality, usability, reliability, and effectiveness in enhancing motorcycle rider safety. The results of the testing and evaluation were used to determine the capability of the system in reducing accident risks caused by rider impairment.

IV. RESULTS AND DISCUSSION

System Implementation

The AI-Based Multi-State Driver Monitoring System was successfully implemented through a wearable smart helmet integrated with sensors, microcontrollers, and wireless communication modules. The final hardware setup included an MQ-3 alcohol sensor, IR sensors for head and eye detection, Arduino microcontrollers, NRF24L01 wireless communication modules, a buzzer, a relay module, a capacitor for power stabilization, and a power supply. All hardware and software components were assembled and programmed to operate as a unified real-time safety monitoring system.

Drowsiness detection was implemented using the IR eye sensor, which continuously monitored eye-closure duration to identify possible fatigue conditions. Alcohol detection was performed using the MQ-3 sensor, which measured alcohol concentration from the rider's breath. The alert mechanism was implemented through a buzzer that automatically activated whenever unsafe riding conditions were detected. Meanwhile, the engine interlock mechanism was implemented using a relay module that controlled the connection and disconnection of the motorcycle ignition system.
The implemented system enabled continuous monitoring of rider condition and automatic activation of safety responses during operation. Communication between the helmet unit and the receiver unit was successfully established through the NRF24L01 wireless communication modules, allowing real-time transmission of monitoring signals and engine control commands. The capacitor also provided stable power regulation to support reliable wireless communication and continuous system operation.

The completed prototype functioned as an integrated wearable safety system capable of detecting unsafe rider conditions, activating warning alerts, and controlling motorcycle operation automatically. The successful implementation of the system demonstrated the practical application of embedded sensors, wireless communication, and rule-based artificial intelligence within a smart helmet platform for motorcycle safety enhancement.

Evaluation Results

Category	Mean	Interpretation
Comfort	4.53	Strongly Agree
Usability	4.53	Strongly Agree
Alert Effectiveness	4.60	Strongly Agree
Reliability	4.38	Agree
Safety Impact	4.58	Strongly Agree
Overall Mean	**4.53**	**Strongly Agree**

The table presents the overall evaluation results of the AI-Based Multi-State Driver Monitoring System based on the respondents' assessment of comfort, usability, alert effectiveness, reliability, and safety impact. The system obtained an overall mean of 4.53 interpreted as "Strongly Agree," indicating that the respondents positively accepted the developed smart helmet system. The results show that the system successfully achieved its purpose of providing real-time rider monitoring and automated safety responses to reduce accidents caused by drowsiness and alcohol intoxication. These findings confirm that the methodology and system implementation effectively addressed the identified transportation safety problem. The evaluation results also demonstrate that the integration of embedded sensors, wireless communication, and rule-based artificial intelligence contributed to the overall effectiveness of the system.

The table further presents that comfort obtained a mean score of 4.53 interpreted as "Strongly Agree." This indicates that respondents considered the helmet comfortable to wear despite the integration of electronic components and sensors. The result suggests that the placement of the hardware components did not significantly interfere with rider movement and usability. Similar findings were reported by Islam et al. (2023) [6], who emphasized that wearable safety systems must maintain user comfort while supporting continuous monitoring functionality. The high comfort rating demonstrates that the developed smart helmet is practical for real-world transportation applications.

In terms of usability, the table presents a mean score of 4.53 interpreted as "Strongly Agree." Respondents found the system easy to use, understandable, and capable of operating automatically without requiring manual interaction from the rider. These findings are consistent with the study of Reyes and Bautista (2023) [13], which highlighted that Arduino-based embedded monitoring systems provide practical and user-friendly transportation safety solutions. The high usability result indicates that the developed methodology successfully produced a system capable of efficient and convenient real-time operation. This further suggests that the smart helmet can be effectively utilized in actual riding conditions.

The table also presents that alert effectiveness obtained the highest mean score of 4.60 interpreted as "Strongly Agree." Respondents strongly agreed that the buzzer alert was noticeable, activated at the appropriate time, and increased rider awareness during unsafe conditions. These findings support the study of Salazar et al. (2022) [14], which showed that embedded warning systems improve rider response and accident prevention through immediate safety alerts. The result confirms that the implemented alert mechanism effectively performed its intended purpose within the developed methodology. This demonstrates the importance of automated warning systems in proactive motorcycle safety technologies.

Meanwhile, reliability obtained a mean score of 4.38 interpreted as "Agree," which was slightly lower compared to the other evaluation categories. Although respondents still considered the system reliable and responsive, minor variations in sensor accuracy and environmental conditions may have influenced system consistency during testing. Similar findings were observed by Navarro and Cruz (2022) [12], who emphasized that reliable embedded monitoring systems require accurate sensor processing and consistent decision-making to improve system performance. Despite these limitations, the system still demonstrated stable operation and acceptable reliability during real-time monitoring. The findings indicate that additional calibration and optimization may further improve future system performance.

Lastly, the table presents that safety impact obtained a mean score of 4.58 interpreted as "Strongly Agree." Respondents agreed that the system effectively improved rider safety, prevented unsafe riding conditions, and increased awareness of the risks associated with drowsiness and alcohol intoxication. These findings are consistent with the studies of Vanaja et al. (2023) [17] and Santos et al. (2023) [15], which concluded that smart helmet technologies with automated monitoring and safety enforcement mechanisms contribute significantly to accident prevention. The high safety impact rating demonstrates that the developed AI-based smart helmet has strong potential for real-world transportation safety applications. Overall, the evaluation results confirm that the system is effective, acceptable, and beneficial for proactive motorcycle accident prevention.

V. CONCLUSION

This study successfully developed and evaluated an AI-based multi-state driver-monitoring system to enhance motor vehicle safety. The system effectively detects rider impairment conditions such as drowsiness and alcohol intoxication using embedded sensors and a rule-based decision algorithm. It provides real-time monitoring and immediate safety responses to reduce the risk of accidents.

All objectives of the study were achieved through the successful integration of hardware and software components. The system demonstrated reliable detection, acceptable response time, and consistent performance during testing. The inclusion of alert mechanisms and engine interlock functionality strengthens its capability to prevent unsafe motorcycle operation.

Evaluation results indicated that the system is user-friendly, functional, and beneficial for improving rider safety. Respondents provided positive feedback on usability, alert effectiveness, and overall system performance. These findings highlight the system's potential for practical application and future improvements in intelligent safety technologies

The integration of multiple safety features enhances overall system effectiveness. The system also demonstrates the practicality of using a rule-based approach for real-time monitoring. It provides a strong foundation for future improvements and wider application. Furthermore, the study confirms that embedded monitoring technologies can serve as effective tools in promoting transportation safety and reducing accident-related risks. The developed system also opens opportunities for future researchers to enhance wearable safety devices through improved sensors, artificial intelligence, and wireless communication technologies.

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