Design and Development of an Energy Harvesting-Based Self-Powered Smart Helmet Using Solar, Thermal, and Wind Energy with Accident Detection and Airbag Deployment System for Enhanced Road Safety

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Publication Date: 2025/10/18

Abstract: This project presents an innovative energy-harvesting smart helmet designed to enhance both safety and sustainability for two-wheeler riders. The system generates and stores electrical energy from three different renewable sources integrated into the helmet—solar, thermal, and wind energy. A solar glass panel on the visor converts sunlight into electricity, while a thermoelectric generator (TEG) mounted on the top utilizes temperature differences through a heat-absorbing layer to produce power. Additionally, a compact air turbine with a mini generator at the front converts airflow during motion into electrical energy. The collected energy is regulated through capacitors and stored in a lithium-ion battery, which can also function as a power bank for external use. The stored power supports multiple safety and automation features. The helmet includes motion and distance sensors to detect accidents, automatically deploying three reusable airbags positioned at the front, right, and left sides in case of a severe impact. In critical situations, the system sends an emergency alert, including a call and GPS location, to registered contacts. The helmet also ensures rider compliance through a smart interlock mechanism—if the helmet is not worn, the vehicle ignition remains disabled, similar to a car's lock–unlock system. Furthermore, an automatic red safety light activates during low-light conditions for better night visibility. .This multifunctional helmet not only ensures rider safety but also demonstrates an effective approach to self-powered safety systems, utilizing renewable energy to enhance the reliability and independence of protective gear for motorcyclists.

Keywords: *Energy Harvesting, Smart Helmet, Thermoelectric Generator, Solar Glass, Air Turbine, Lithium-Ion Battery, Motion Sensor, Accident Detection, Reusable Airbag, Renewable Energy, Rider Safety.*

How to Cite: Dnyaneshwari V. Gophane; Anand D. Kamble; Suraj S. Gele; Vijay A. Abhivant; Meghnath L. Khatal; Rohan S. Lingade; Purva S. Kole; Tanuja N. Mane; Shrinath G. Fadtare; Sujit S. Khandagale (2025) Design and Development of an Energy Harvesting-Based Self-Powered Smart Helmet Using Solar, Thermal, and Wind Energy with Accident Detection and Airbag Deployment System for Enhanced Road Safety. *International Journal of Innovative Science and Research Technology*, 10(10), 955-958. https://doi.org/10.38124/ijisrt/25oct678

I. INTRODUCTION

Road accidents involving two-wheelers are among the major causes of fatalities and injuries worldwide. Despite advancements in automotive safety systems, two-wheeler riders remain highly vulnerable during accidents due to limited protection and lack of advanced safety features. Helmets play a crucial role in minimizing head injuries; however, conventional helmets are limited to providing only physical protection without any active safety or intelligent response mechanisms. To address these challenges, the concept of a smart helmet integrated with energy-harvesting and safety technologies has been proposed. The aim of this project is to design and develop a helmet that not only ensures rider safety but also generates and stores electrical energy from multiple renewable sources. The system utilizes solar, thermal, and wind energy through components such as a solar glass panel, thermoelectric generator (TEG), and a mini air turbine. The energy harvested is stored in a lithium-ion

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25oct678

battery via capacitors and can also be used for additional functionalities like powering sensors and emergency systems.

This stored energy supports intelligent safety features such as accident detection using motion and distance sensors, automatic airbag deployment, and emergency communication through message or call alerts with GPS location. Moreover, the helmet is designed with a vehicle interlocking mechanism that prevents the vehicle from starting unless the rider is wearing the helmet, thus promoting safe driving habits. An automatic red safety light is also incorporated, which activates in low-light conditions to improve visibility during night riding. Hence, this smart energy-harvesting helmet not only contributes to the rider's safety but also represents a sustainable and self-powered solution, utilizing renewable energy to enhance the reliability, comfort, and intelligence of personal protective equipment for two-wheeler riders.

II. RESEARCH GAP

Many researchers have focused on developing smart helmets that include features such as accident detection, alcohol sensing, and GPS tracking to enhance rider safety. However, most of these systems rely entirely on external power sources or batteries that require frequent charging, which limits their practicality and long-term usability. Similarly, while some studies have explored renewable energy harvesting for small electronic devices, the integration of multiple energy sources within a helmet remains underexplored.

Existing designs often emphasize either safety or power generation, but not both in a single, efficient system. Few attempts have been made to combine solar, thermal, and wind energy harvesting mechanisms to create a self-sustaining helmet capable of powering multiple safety features simultaneously. Additionally, the deployment of reusable airbags for impact protection and automated emergency alerts with vehicle interlocking systems has not been effectively combined into one integrated design.

Therefore, there exists a clear research gap in developing a multifunctional, energy-harvesting helmet that not only ensures rider safety through intelligent sensing and protection mechanisms but also operates independently using renewable energy sources, eliminating dependency on conventional charging methods.

III. PROBLEM STATEMENT

Two-wheeler riders face a high risk of severe injuries or fatalities during accidents due to inadequate safety systems and limited protective technology. Conventional helmets provide only passive protection and lack intelligent features such as accident detection, automatic alerts, or energy self-sufficiency. Moreover, existing smart helmets depend on external charging sources, making them inconvenient and less reliable for continuous use.

There is a need for a helmet that can actively enhance rider safety while remaining self-powered and sustainable. The proposed system aims to develop an energy-harvesting smart helmet that utilizes solar, thermal, and wind energy to generate and store power for operating integrated safety mechanisms such as accident detection, automatic airbag deployment, emergency communication, and vehicle interlocking, ensuring both protection and power independence for the rider.

IV. OBJECTIVES

- To design and develop a smart helmet capable of harvesting energy from multiple renewable sources such as solar, thermal, and wind.
- To store the generated energy efficiently in a lithium-ion battery through capacitors for continuous power supply.
- To implement safety features such as accident detection using motion and distance sensors, and automatic deployment of reusable airbags.
- To integrate an emergency alert system that sends the rider's current location and call/message to registered contacts in case of a major accident.
- To develop a vehicle interlocking mechanism that prevents vehicle ignition when the helmet is not worn, ensuring rider safety and discipline.

V. DESIGN AND DEVELOPMENT

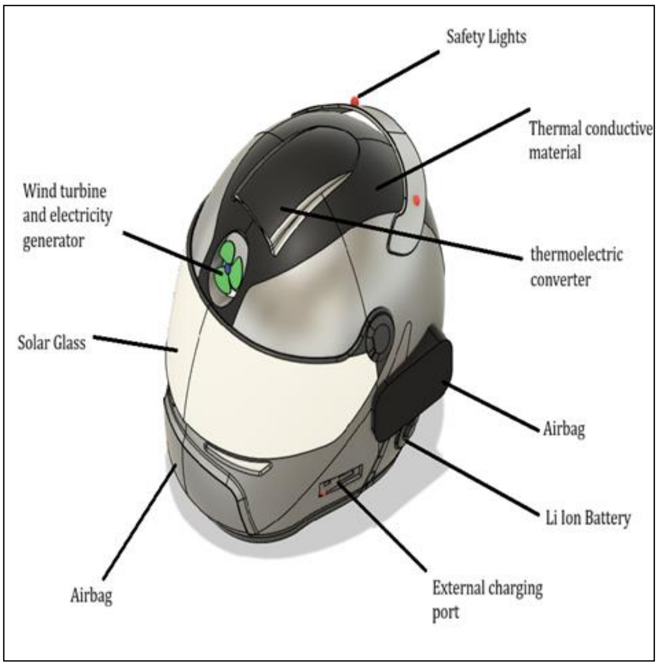

Fig 1 Design And Development

This project focuses on developing a smart helmet that enhances rider safety while generating its own power from renewable sources. The helmet harvests energy from a solar glass panel, a thermoelectric generator (TEG), and a small air turbine. The generated power is stored in a lithium-ion battery through capacitors and can also be used as a power bank.The stored energy operates safety features like accident detection, automatic airbag deployment, night safety light, and an emergency alert system that sends the rider's location to registered contacts. It also includes a vehicle interlock system that prevents ignition if the helmet is not worn. This design provides a compact, self-powered, and intelligent safety solution for two-wheeler riders.

VI. WORKING PRINCIPLE

The smart helmet operates on the principle of multi-source energy harvesting and intelligent safety response. It collects energy from three renewable sources solar, thermal, and wind and utilizes the stored power to activate various safety functions.

When the rider wears the helmet, a button inside gets pressed, completing the power circuit and activating the system. The solar glass panel converts sunlight into electrical energy, the thermoelectric generator (TEG) produces power from the temperature difference between the heat-absorbing outer surface and the inner layer, and the air turbine generates electricity from airflow during motion. The combined output from these sources is regulated through capacitors and stored in a lithium-ion battery.

This stored energy powers the sensors and electronic components. Motion and distance sensors continuously monitor the rider's movement and detect any sudden impact or fall. In case of a major accident, the helmet automatically deploys three airbags positioned at the front, right, and left sides, and sends an emergency message or call with the rider's GPS location to registered contacts. The red safety light turns on automatically at night using a light sensor, ensuring better visibility.

Additionally, the helmet includes a vehicle interlocking system if the helmet is not worn, the vehicle will not start. Thus, the helmet efficiently combines renewable energy harvesting with advanced safety mechanisms to provide reliable protection and sustainability for two-wheeler riders.

VII. RESULT AND OBSERVATION

The proposed energy-harvesting smart helmet was successfully designed and tested to validate its performance in both energy generation and safety functionalities. The integration of three renewable energy sources—solar, thermal, and wind—proved to be effective for self-sustained operation. During experimentation, the solar glass panel generated consistent electrical output under sunlight, contributing the highest share of the total energy. The thermoelectric generator (TEG) produced measurable voltage when a temperature difference was created between the heat-absorbing top layer and the inner surface of the helmet. The air turbine, equipped with a micro-generator, efficiently converted airflow during motion into additional electrical energy, further supporting the charging system.

The regulated energy from all sources was stabilized through capacitors and stored in a lithium-ion battery. The stored power was sufficient to operate the helmet's electronic systems, including motion and distance sensors, the airbag deployment unit, red safety light, and communication modules. The battery also demonstrated the capability to act as a power bank for small external devices.

The accident detection unit performed accurately, identifying sudden changes in acceleration and position. Upon detection of a simulated impact, the airbags deployed quickly at the front, right, and left sides, providing effective cushioning. The emergency alert system successfully transmitted the rider's location and emergency message to registered contact numbers within seconds of activation. The automatic red safety light operated reliably, turning on only in low-light or night conditions through the light sensor mechanism.

Additionally, the helmet's interlock system functioned properly, preventing the vehicle from starting unless the helmet was worn, thereby ensuring safety compliance. The overall system worked efficiently, proving that renewable energy can effectively power essential safety components. The observations confirm that this design not only enhances rider protection but also promotes the use of clean energy for smart and sustainable transportation safety solutions.

VIII. APPLICATIONS

- *Two-Wheeler Safety Equipment*
  The helmet can be used by motorbike and scooter riders to enhance personal safety through automatic airbag deployment and accident detection features.

- *Emergency Response System*
  Useful for automatic accident alerts, sending messages and live location to emergency contacts or rescue services, improving response time.

- *Energy-Harvesting Demonstration Model*
  Can serve as a practical educational prototype for demonstrating multi-source renewable energy harvesting in engineering and research institutions.

- *Vehicle Interlocking Mechanism*
  Applicable for integration with two-wheelers to ensure riders wear helmets before ignition, promoting road safety and discipline.

- *Smart Helmet for Delivery and Patrol Riders*
  Ideal for delivery personnel, traffic police, and long-distance riders who require continuous protection and reliable safety alerts.

- *Portable Power Source*
  The helmet's lithium-ion battery can be used as a small portable power bank to charge low-power electronic devices like smartphones or trackers.

- *Night Visibility and Safety Enhancement*
  The automatic red light improves visibility for riders in low-light or night conditions, reducing accident risks.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25oct678

IX. FUTURE SCOPE

The energy-harvesting smart helmet can be further improved by integrating advanced technologies to increase efficiency and functionality. Future versions can include higher-efficiency solar cells and thermoelectric materials to enhance power generation even in low sunlight or temperature conditions. The air turbine design can be optimized aerodynamically to produce more power at lower speeds without increasing drag or noise.

The communication system can be upgraded with IoT-based connectivity using 4G or 5G modules for real-time accident reporting and cloud-based data storage. Artificial intelligence can be incorporated to analyse riding patterns and predict potential accident risks. The helmet can also be made compatible with smart vehicles through wireless data exchange, enhancing coordinated safety responses.

Improved lightweight materials and flexible electronics can make the helmet more comfortable and reduce overall weight. The use of transparent solar films or perovskite solar cells on the visor can increase power output without affecting visibility. With further development, this helmet can set a new standard for smart, self-powered, and safety-oriented gear for two-wheeler riders, contributing to safer and more sustainable transportation systems.

X. CONCLUSION

The energy-harvesting smart helmet successfully combines safety, sustainability, and innovation in a single system designed for two-wheeler riders. By utilizing three renewable energy sources—solar, thermal, and wind—the helmet efficiently generates and stores electrical energy to power its smart safety features. The integration of motion and distance sensors enables accurate accident detection, while the automatic deployment of airbags and emergency alert system ensures quick response in critical situations.

The helmet's vehicle interlocking mechanism promotes disciplined riding behavior by preventing ignition unless the helmet is worn, thus encouraging consistent helmet usage. Additional features such as the automatic night safety light and portable power bank functionality enhance the overall practicality and user experience.

Through effective energy management and multifunctional design, this smart helmet demonstrates a self-sustaining and intelligent approach to rider protection. It represents a significant step forward in combining renewable energy technology with road safety innovation, contributing to a safer and smarter future for two-wheeler transportation.

ACKNOLEDGEMENT

This project was successfully completed through the collective effort, coordination, and dedication of the student team. Every stage, from conceptualization and design to modeling and documentation, was carried out through collaborative teamwork and shared responsibilities. We extend our sincere thanks to the SVERI's College of Engineering, Pandharpur, for providing the necessary resources and a supportive environment that enabled us to bring this concept to life. Lastly, we are grateful to our families and friends for their cooperation, dedication, and moral support, which contributed significantly to the successful completion of this work.

REFERNCES

[1]. Sharma, R. Singh, and S. Verma, "Design and Implementation of Smart Helmet for Accident Detection and Safety," *International Journal of Engineering Research & Technology (IJERT)*, vol. 9, no. 6, pp. 112–116, 2022.
[2]. M. Kumar and P. S. Rao, "Development of a Solar Powered Smart Helmet for Rider Safety," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 11, no. 4, pp. 2458–2464, 2023.
[3]. S. Patel and D. Mehta, "IoT-Based Accident Detection and Alert System Using Smart Helmet," *IEEE Access*, vol. 8, pp. 159784–159793, 2021.
[4]. P. Gupta and A. Chatterjee, "Multi-Source Energy Harvesting Systems: A Review," *Renewable and Sustainable Energy Reviews*, vol. 143, p. 110897, 2021.
[5]. N. Yadav, T. Kaur, and V. Bansal, "Thermoelectric Generators: Principles and Applications," *Journal of Electrical Engineering and Technology*, vol. 17, no. 2, pp. 657–665, 2022.
[6]. R. Prakash and K. Srivastava, "Integration of Renewable Energy Sources for Portable Electronic Devices," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 10, no. 9, pp. 5402–5409, 2021.
[7]. B. S. Raj and H. Naik, "Design and Fabrication of Air Turbine-Based Energy Harvesting Helmet," *Journal of Mechanical and Energy Engineering*, vol. 5, no. 3, pp. 145–150, 2022.