A Review of Smart Safety Jackets: Enhancing Worker Safety Across Industries Through Real-Time Monitoring

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***Abstract*—This research investigates the smart safety jacket that service technicians across coal mining, construction emergency response use for their dangerous work risks. Real-time data from hazardous gas levels and heart rate and body temperature, and motion detects is collected through sensors on this jacket that send data to central control centers using Wi-Fi GSM and 5G. Workers receive improved protection through safety jacket technology because the devices track GPS locations and activate warning signals to prompt immediate emergency actions in high-risk areas. The future development of 5G alongside AI and blockchain technologies will boost the smart safety jacket's importance for industrial hazard protection while improving operational efficiency which ensures employee safety in dangerous areas.**

***Keywords*— Smart Safety Jacket, Wearable Technology, Coal Mining, Internet of Things (IoT), Blockchain Security**

1. INTRODUCTION

The smart safety jacket represents an advanced safety solution that improves industrial worker safety when personnel operate in risky coal mining, construction, or factory environments. The wearable device operates with various sensors that detect essential indicators from gas toxicity to heart-rate shifts, temperature changes, and worker physical movements. Monitoring systems receive real-time data from sensors embedded in jackets, enabling emergency response actions to be made in a timely fashion. Modern occupational safety technology relies heavily on smart safety jackets because research and development have accelerated due to the growing workplace safety needs in dangerous environments. A thorough examination of smart safety jacket technology presents the study of their construction design, functional principles, and advancements. The paper examines different smart jacket systems developed for hazardous work sites by evaluating critical elements that include sensors, communication approaches, power management systems, and live data processing abilities. The research examines existing system constraints and recommends changes to boost smart safety jacket effectiveness while making them more reliable. Researchers and industry professionals should refine protective wearables through their understanding of modern advances and present conditions to achieve peak worker protection.

2. OVERVIEW OF SMART SAFETY JACKETS

Smart safety jackets unite various advanced technologies to monitor workers' body condition together with environmental factors in real time. Active environmental information collection and analysis through smart jackets serve to trigger safety alerts whenever hazardous conditions appear in the surroundings. The preventative safety method reduces workplace accidents in advance through active monitoring instead of relying on post-incident recovery measures. The jackets contain integrated elements that combine to offer immediate safety tracking capabilities. The jacket incorporates

various internal sensors that identify toxic air elements and perform environmental measurements of temperature and humidity and track bodily information such as heart rate and vital signs together with motion monitoring for identifying hazardous events including falls and prolonged inactivity. The main unit of the processor operates as a central processor to control data entry while maintaining real-time connections with monitoring networks. Real-time data transmission happens through wireless communication modules consisting of Wi-Fi and Bluetooth and ZigBee and GSM and 5G systems to enable quick supervisor and safety officer responses to detected safety risks. The jacket needs energy-efficient battery technologies to maximize its operational time because the power system uses rechargeable batteries. A combination of buzzers and vibration alarms alongside mobile alerts enables employees to receive fast caution about hazardous situations so they can prevent accidents before they become dangerous incidents. The integration of these features makes smart safety jackets transform into crucial step in personal protective equipment (PPE). Multiple obstacles persist regarding smart safety jackets despite their extensive advantages because they suffer from connection issues in distant places and dark environments and their batteries drain quickly while also demanding more precise sensor readings. Solving these technical impediments becomes vital for developing the superior performance of these new protective wearable technologies.[1]

3. FEATURES AND TECHNOLOGIES IN SMART JACKETS

3.1 Sensors Used

Figure 3.1 MQ series gas sensors [9]

Multiple sensors built into smart safety jackets detect particular environmental and human body elements. The safety hardware continuously monitors obstacles in the environment while generating immediate data sets for analytical purposes to protect workers. Gas sensors represent essential elements of smart safety systems because they identify dangerous gases including carbon monoxide and methane as well as sulfur dioxide that exist in industrial and mining facilities. The presence of these gases creates serious health dangers because coming across these gases without detection can result in fatal consequences. MQ-2, MQ-4, and MQ-7 together with MQ-7 compose the MQ series which functions as sensitive standard equipment for detecting particular gases throughout various industries. Workers need temperature sensors that check both environmental and body temperature to protect them from dangerous extreme heat and cold conditions leading to heatstroke or hypothermia. The Photoplethysmography (PPG) based heart rate monitors analyze worker's cardiovascular health by detecting abnormal signals that suggest both physical and mental exhaustion alongside dangerous medical conditions. Built-in accelerometers operate with gyroscopes to track rapid body movements and immobility because these signals indicate possible situations such as accidents or unconsciousness. Real- time location tracking is enabled by GPS modules to guarantee personnel safety in dangerous work environments through immediate emergency location identification. Smart safety jackets become complete monitoring systems through sensor integration because they perform a continuous evaluation of both worker biological conditions and situational environmental factors. A centralized monitoring system receives and analyzes data from the collected information for threat detection and starts emergency precautions. [2]

3.2 Communication & Connectivity

Figure 3.2 GSM Module [10]

The durability of smart safety jackets depends directly on their real-time operational data transmission reliability and efficiency. Multiple connecting protocols serve to enable continual communications between the jacket and monitoring network control systems. The wireless Wi-Fi communication system functions as an established data transfer method in industrial spaces where it combines quick speeds with dependable network connections. Bluetooth enables limited-range information transfer from mobile devices to control units at minimal power expense. ZigBee establishes its utility in extended communication networks because it operates using low power consumption with mesh capabilities for multiple smart jackets and sensors. Through GSM and cellular networks, users can maintain remote data transfer connectivity across locations that lack Wi-Fi connectivity. Future model implementations of 5G technology will drive connectivity excellence through rapid data transmission and extremely brief response time that benefits real-time industrial monitoring within changing operational areas. Smart safety jackets establish continuous data links with monitoring systems through these communication technologies which permit safety personnel to track both worker states and environmental hazards in real-time.

Reliable hybrid network solutions emerged as the solution for tunnel mine and remote site connectivity needs because different communication protocols provide the best possible reliability and coverage. [3]

3.3 Power Supply & Energy Efficiency

Figure 3.3 Lithium Ion Batteries [11]

Power supply functions as an essential parameter during smart safety jacket implementation and operation. The majority of jackets use rechargeable lithium-ion batteries since they provide a good compromise between power capability and weight reduction. System design requires energy efficiency to be a primary focus because multiple sensors running with communication modules simultaneously deplete battery power quickly. The life of the battery extends through multiple energy-saving techniques. The system incorporates several features like sensor cycle optimization and power-efficient communication protocols and microcontroller designs with reduced energy consumption. The upcoming smart jackets will explore solar energy and kinetic energy harvesting as their power sources so they can generate power from worker movement yet maintain their lightweight nature. Smart jackets achieve extended operation by being energy efficient which allows them to monitor safety without needing frequent battery charges in dangerous conditions. [3][4]

4. EVALUATION AND INTERPRETATION

The comparison table provides a detailed overview of various smart jacket designs and their features, particularly in hazardous industries like coal mining. Each study analyzed has unique strengths and limitations shaped by the technology available at the time of its development and the specific industrial needs it aimed to address.

4.1 Strengths of Smart Jacket Technologies

Real-Time Data Processing stands as a foremost advantage because smart safety jackets perform instant processing and data transmission. Real-time monitoring of environmental conditions as well as physiological indicators happen continuously through these smart jackets so emergency responses can happen quickly. The analysis and remote accessibility capabilities of cloud platforms make IoT-based systems more powerful through data storage functions. Modern smart jackets integrate all-inclusive sensor systems that combine gas sensors with heart rate monitors and temperature detectors as well as GPS modules. A full observation of worker safety becomes possible through the integrated system because it tracks various data points at once. A merging of multiple sensors offers prompt identification of different risks such as toxic gas exposure together with overheating or sudden falls. Full monitoring is essential for dangerous working conditions which contain various hazards. The effective communication capabilities of smart jackets form a fundamental feature among their vital components. Workers and supervisors receive notifications through two methods: cloud-based alerts together with SMS messages and automatic alarms which alert them of potential risks. Faster evacuation or corrective actions happen through immediate notifications which decrease the risk of fatal injuries or deaths. Smart jackets employ multiple communication

4.2 Limitations of Current Systems

Connectivity Issues: While real-time monitoring is a major benefit, underground work environments, such as coal mines, often face connectivity challenges. Wireless communication technologies, including Wi-Fi and cellular networks, may not function effectively in such locations, reducing the efficiency of smart jackets. Efforts are being made to mitigate this issue through advancements in 5G technology and hybrid communication models that integrate Bluetooth, LoRa, and satellite connectivity. Energy Consumption: A critical challenge faced by smart jackets is high power consumption. Running multiple sensors simultaneously requires substantial energy, which can lead to frequent battery depletion. Future developments should focus on energy-efficient designs, including the use of low-power processors, energy harvesting techniques, and improved battery technologies to extend operational hours without increasing the weight of the jackets. Sensor Accuracy: To protect workers effectively the smart jackets must include sensors which deliver precise and dependable results. Incorrect sensor readings (false positives) together with sensing failures present risks to the workers. The development of accurate sensors requires sharp calibration procedures and intelligent data verification algorithms and field-based rigorous testing to achieve high reliability support workers in dangerous environments. Testing platforms alongside upgraded sensor systems need further improvement to minimize accidents while adequately identifying possible risks. [4], [5],[6]

4.3 Future Directions

The application of artificial intelligence (AI) and machine learning makes smart jackets capable of improving their capabilities. These systems use historical data to discover safety-related patterns for pre-incident danger detection purposes. The jacket can issue warnings to workers about upcoming hazards before potentially dangerous situations materialize. Predictive alert technology enables people to take proactive measures against accidents thus transforming worker safety from reactive to proactive response. Integration with Advanced Networks: As 5G and upcoming 6G technologies become widespread, smart jackets will benefit from improved connectivity and faster data transmission. This will address existing communication challenges in remote or underground locations, ensuring seamless monitoring and real-time responsiveness. Future research will concentrate on combining safety systems into one wearable environment. Smart jackets would function in harmony with protective equipment like helmets and gloves together with work boots in order to establish a complete safety system. Such a multisystem approach to hazard detection and emergency response

through these ecosystems improves total worker safety performance. [5], [6]

5. GAPS AND FUTURE SCOPE

Enhancements have been made to smart safety jackets however multiple challenges persist in their development process and market acceptance. Additional technological research must be conducted to effectively resolve the identified gaps in the development and adoption of smart safety jackets. [7], [8]

5.1 Interoperability: Wearable technology needs complete system interoperability because its continuous development requires consistent components. The integration of smart jackets and helmets can exchange workplace data efficiently based on creating uninterrupted device communication. The installation of standard communication protocols ensures integration between different vendor products that operate safety equipment

5.2 Enhanced Power Management: Recent power management system requirements grow more significant because users demand increased battery longevity and power consumption efficiency. Future research on sustainable power systems needs to study solar power systems together with kinetic power generation along with wireless energy distribution technologies. The production of better electronic elements that preserve operational ability stands as a prerequisite to reducing power consumption in electronic devices.

5.3 User Experience: Comfort together with ease of use serve as essential factors that determine how widely smart jackets will be accepted by users. Workers will not extend their use of jackets that are either too heavy bulky or uncomfortable to wear. Future smart jacket designs need to prioritize ergonomic elements, lightweight materials, and flexible fabrics to reach maximum comfort in addition to easy usage. A perfect balance between functionality and user-friendliness stands out as the main factor for raising smart jacket adoption rates.

5. COMPARATIVE ANALYSIS OF SMART SAFETY JACKETS

Various worldwide safety jacket developers created hundreds of smart designs that include different sensor systems and technological components to enhance workplace safety. The current assessment analyzes several smart safety jackets that demonstrate their advantages alongside their shortcomings as well as potential enhancement possibilities. The technology includes a gas sensor alongside an accelerometer and GPS tracking systems which provide thorough environmental analysis with worker position detection capabilities. The device faces a limitation because its high power usage leads to brief operating periods. An advanced system that incorporates machine learning predictions of dangerous situations encounters difficulties because of the uncertainty of its prediction methods. Scientific research must now focus on improving these advanced features so smart safety jackets achieve better field success. Additional sections will examine essential assessments combined with present technology shortcomings and suggest research paths to increase smart safety jacket effectiveness alongside industrial adoption. [1][8]

Paper Title & Year	Unique Features & Advancements	Limitations & Future Scope
Telemetry of Coal Miners Using Smart Jacket (2023)	Threshold-based Gas Alerts, GPS Tracking	Limited connectivity in underground mines.
Smart Wearable Safety Jacket Design for Coal Miners (2023)	Helmet Integration, Fire Detection, Vibration Sensor	Power consumption is high.
Advancing Safety Standards with Real-Time Embedded Smart Jacket (2024)	Fall Detection, Health Monitoring, AI- Driven Alerts	Needs better AI integration.
Smart Jacket for the Coal Miners Based on WSN & WoT (2017)	Web of Things (WoT) Integration for Remote Access	Latency in remote communication.
IoT-Based Coal Mine Safety Monitoring System (2019)	AI-Based Anomaly Detection for Predictive Safety	Lacks predictive analytics.
Zigbee and Wi-Fi Based Mine Safety Application (2014)	ZigBee & Wi-Fi Hybrid Network for Robust Communication	Short-range communication.

6. CONCLUSION

Nowadays smart safety jackets emerged as a breakthrough in personal protective equipment which brings real-time monitoring together with enhanced safety capabilities to dangerous working environments. These jackets dominate the market through their combination of advanced sensors and wireless communication methods and cloud-based platforms to deliver security protection for workers operating in mining sites construction areas and fire scenarios. The main issues to address about smart safety jackets include restricted battery duration and unreliable sensor readings together with networking problems. Necessary innovations in research and technology development must solve the current limitations to boost the performance of smart safety jackets. The industry will implement AI-based predictive analysis together with extended energy capacity along with next- generation communication infrastructure such as 5G and 6G. Smart jackets will achieve superior effectiveness for worker safety and well-being by resolving existing problems through the integration of emerging technologies. Standard implementation of smart safety jackets in high-risk industries requires ongoing improvements of these devices along with multidisciplinary collaboration efforts.

REFRENCES

[1] Raj B. S., Sahana, G. B. M., Abhishek, Nayana R., Dhanraj B. M., and Yeshwanth D. S., "Advancing Safety Standards with Real-Time Embedded Smart Jacket," *Int. Adv. Res. J. Sci., Eng. Technol. (IARJSET)*, vol. 11, no. 5, May 2024.

[2] Vanitha U., Aakaash V. S., Arvinth R. A., Ashwin T., and Bhagavathidharshan B., "Telemetry of Coal Miners Using Smart Jacket," *Int. J. Circuits Electron.*, vol. 8, 2023.

[3] M. K. Chandrasekaran, R. Akshaya, U. Ashwini, V. Kamali, and G. S. M. Sakthi, "Smart Wearable Safety Jacket Design for Coal Miners," *Int. J. Progressive Res. Eng. Manag. Sci. (IJPREMS)*, vol. 3, no. 5, May 2023.
[4] Digvijay Guleria, Dheeraj, Sriram Goli, Karthik Gokani, Chadha Konagani, Komal, and Dr. Ajay Roy, "A Smart Wearable Device for Securing the Life of Coal Miners," Dept. of ECE, Lovely Professional University, Punjab, India, 2023.
[5] Er. S. R. Karthiga, S. Harini, M. Lavanya, S. Shahana, and S. Hazira, "Smart Helmet Security System for Industrial Miners Using IoT," [Online]. Available: *[URL not specified]*
[6] M. Adhithiyan, D. Gopalakrishnan, and R. K. Kapilavani, "Smart Safety Helmet for Coal Mine Workers," 2023. [Online]. Available: *[URL not specified]*
[7] Mr. M. Balaji, S. Monika, N. Akshaya, R. Priya Soorya, and Swathi, "Smart Wearable Safety Jacket Design for Coal Miners," 2023. [Online]. Available: *[URL not specified]*
[8] Sant Gadge Baba Amravati University, *Project Report on Smart Safety Jacket for Coal-Miners*, Amravati, 2022.
[9] Kunkune, "Gas Detection Sensors - Arduino Sensor Clear," Nov. 2022. [Online]. Available: https://www.kunkune.com
[10] FlyRobo, "SIM800L GPRS GSM Module Micro SIM Card Quad Band TTL Serial Port," [Online]. Available: https://www.flyrobo.in
[11] Enix Power Solutions, "Lithium-ion Standard Battery," Jun. 2021. [Online]. Available: https://www.enix-energies.com