iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 2026 Issue: Conference Month of publication: May 2026

DOI: https://doi.org/10.22214/ijraset.2026.83195

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com
National Conference on Integrated Approaches to Sustainable Innovation 2026 (IASI 2026)

Real-Time Accident Prevention in Power Plants Using IoT

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Abstract—Power plants are critical to energy production but pose significant safety risks due to hazardous environments, equipment failures, and human errors. The integration of the Internet of Things (IoT) provides an innovative framework for real-time accident prevention by enabling continuous monitoring, data analysis, and automated safety interventions. IoT systems utilize interconnected sensors to track critical parameters such as temperature, pressure, vibration, and gas leakage. Real-time data transmission and advanced analytics, powered by artificial intelligence (AI) and machine learning (ML), allow for the early detection of anomalies, predictive maintenance, and swift corrective actions. Additionally, wearable IoT devices ensure worker safety by monitoring their health and location in high-risk areas. While IoT implementation in power plants offers benefits such as enhanced safety, operational efficiency, and cost savings, challenges like cybersecurity vulnerabilities and high setup costs persist. This paper reviews the potential of IoT in minimizing accidents and highlights future directions for secure, scalable, and cost-effective solutions. The findings emphasize that IoT represents a transformative approach to achieving safer and more resilient power plant operations.
Keywords: Power Plant, Internet of Things (IoT), Machine Learning (ML), Artificial Intelligence (AI), Personal Protective Equipment (PPE), Predictive Maintenance, Wearable Devices.

I. INTRODUCTION

Power plants are the backbone of energy generation and play a pivotal role in powering industries, households, and infrastructure [1]. However, their operation involves numerous challenges, particularly in maintaining safety standards to protect workers, equipment, and the environment. Accidents in power plants, such as fires, explosions, gas leaks, and equipment failures, can lead to catastrophic consequences, including loss of life, economic setbacks, and environmental degradation. These incidents highlight the critical need for innovative safety mechanisms to prevent accidents and ensure smooth operations.

In recent years, the Internet of Things (IoT) has emerged as a transformative technology with immense potential in industrial safety applications. IoT integrates sensors, connectivity, data analytics, and automation to create intelligent systems capable of monitoring and responding to risks in real time [2–3]. In power plants, IoT provides a robust framework for accident prevention by enabling continuous monitoring of critical parameters, predictive maintenance, and automated alerts. This ensures not only the safety of personnel but also the optimal functioning of the facility.

The IoT ecosystem in power plants is built around sensors that measure various parameters such as temperature, vibration, gas concentration, humidity, and pressure [1]. These sensors are deployed strategically across machinery, pipelines, and workspaces. Vibration sensors can detect early signs of wear and tear in rotating machinery, while gas sensors monitor the concentration of hazardous gases like methane or carbon monoxide. The data collected is transmitted to central control systems through wireless communication protocols such as Zigbee, LoRaWAN, or 5G networks, as summarized in Table III.

Advanced analytics powered by AI and ML are employed to identify anomalies, predict potential failures, and generate actionable insights. For instance, predictive maintenance algorithms can forecast when a component is likely to fail, enabling timely repairs and preventing costly downtime [3]. Wearable IoT devices, such as smart helmets, wristbands, and vests, monitor the health and location of workers in hazardous environments, ensuring prompt evacuation and assistance in emergencies. Despite the advantages, challenges such as cybersecurity risks, high initial investment costs, and skill requirements persist [5–7]. This paper reviews the potential of IoT in minimizing accidents and highlights future directions for secure, scalable, and cost-effective solutions.

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II. REAL-TIME ACCIDENT PREVENTION IN POWER PLANTS USING IOT

The integration of IoT in power plants leverages interconnected sensors, data analytics, and cloud computing to ensure safety. The overall system architecture, illustrated in Fig. 1, comprises four layers: the physical/sensor layer, the communication layer, the data processing and analytics layer, and the safety response layer.

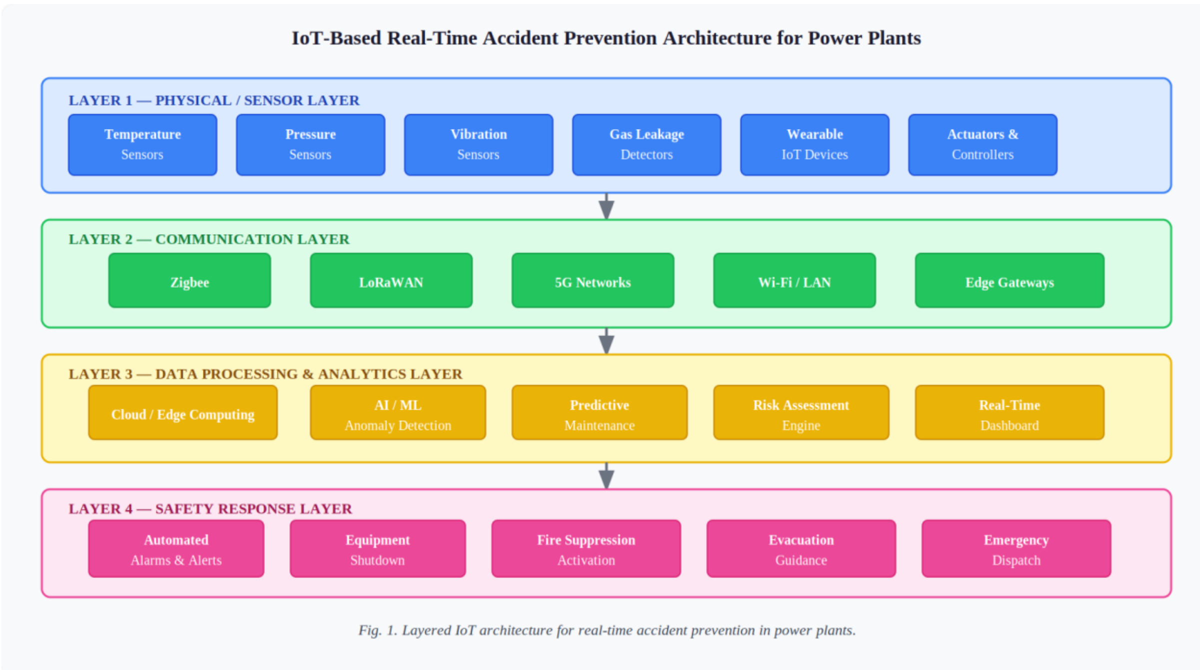

Fig. 1. Layered IoT architecture for real-time accident prevention in power plants.

Sensors deployed across machinery and work environments monitor parameters such as temperature, pressure, vibration, and gas leakage [8–9]. Table I summarizes the key sensor types, the parameters they measure, their primary applications in power plant safety, and the communication protocols they typically employ. Vibration sensors detect abnormal equipment behavior that often precedes mechanical failures, while gas sensors identify toxic or combustible gases and trigger alarms before they reach critical levels.

TABLE I. Key IoT Sensor Types and Their Applications in Power Plant Safety

Sensor Type	Parameter Measured	Application in Power Plant	Communication Protocol	Alert Threshold
Temperature Sensor	Ambient / equipment temperature	Overheating detection in turbines, boilers, transformers	Zigbee, Wi-Fi	> 80°C (critical equipment)
Pressure Sensor	Fluid / gas pressure (bar, PSI)	Pipe burst and boiler pressure monitoring	5G, LoRaWAN	> 150 PSI
Vibration Sensor	Mechanical vibrations (m/s^2)	Wear/tear detection in rotating machinery	Zigbee, Wi-Fi	> 12 mm/s RMS
Gas Leakage Detector	Gas concentration (ppm)	Methane, CO detection; explosion prevention	LoRaWAN, 5G	> 50 ppm (CO)
Wearable Heart Rate	Heart rate (BPM)	Worker health and distress monitoring	Bluetooth, Wi-Fi	< 50 or > 120 BPM

Humidity Sensor	Relative humidity (%)	Moisture detection in electrical rooms	Zigbee	> 80% RH
Infrared Camera	Thermal imaging (°C)	Hot-spot detection on electrical panels	Wi-Fi, 5G	Temp differential > 15°C

IoT systems utilize wireless communication protocols—including Zigbee, LoRaWAN, and 5G—to transmit real-time data to centralized control units. These control systems employ AI and ML algorithms to analyze data, identify anomalies, and recommend corrective actions, thereby reducing reaction times and mitigating accidents effectively.

At the core of IoT systems are sensors and actuators that serve as the first line of defense [12]. If operational parameters exceed safe thresholds, actuators execute safety actions such as shutting down equipment, triggering alarms, or activating fire suppression systems. The real-time decision-making workflow is illustrated in Fig. 2.

Fig. 2. Workflow flowchart for real-time IoT-based accident prevention in power plants

One of the most significant contributions of IoT in accident prevention is the use of AI- and ML-powered analytics [13–15]. IoT systems continuously analyze vast amounts of sensor data to identify patterns, detect anomalies, and predict potential failures. Predictive maintenance algorithms forecast component failures, allowing timely repairs and avoiding unplanned downtime, while AI-driven risk assessment tools evaluate accident likelihood and severity.

Another critical application of IoT in power plants is enhancing worker safety through wearable devices [16]. Smart helmets, wristbands, and vests equipped with IoT sensors monitor workers' health parameters—including heart rate, body temperature, and oxygen levels—and track their location in hazardous areas [4]. The wearable device architecture is illustrated in Fig. 3. Geo-fencing technology further enhances safety by issuing warnings when workers approach restricted or dangerous zones.

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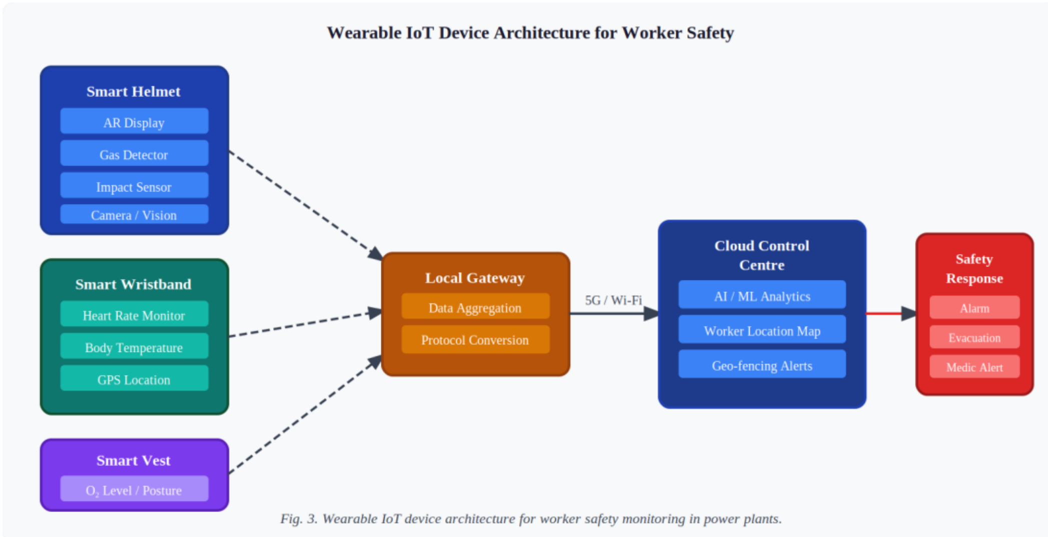

Fig. 3. Wearable IoT device architecture for worker safety monitoring in power plants

Beyond individual safety, IoT enables holistic accident prevention by integrating with fire suppression mechanisms, alarm systems, and evacuation protocols [17–19]. During a gas leak, IoT sensors not only detect the leak but also activate ventilation systems, sound alarms, and guide workers to safe zones. Real-world implementations underscore these benefits: in one instance, abnormal turbine vibrations were detected early, enabling timely maintenance and preventing a critical failure [20–22]; in another, gas sensors identified a methane leak, triggering automatic ventilation and averting a potential explosion.

III. CHALLENGES AND FUTURE DIRECTIONS

The integration of IoT technologies into power plants offers transformative safety benefits, yet its adoption faces significant challenges. Understanding these barriers and corresponding solutions is critical to accelerating deployment.

A. Challenges in Implementing IoT for Accident Prevention

Table II provides a structured overview of the primary challenges encountered in IoT deployment for power plant safety, along with proposed mitigation strategies. The challenges span technical, financial, organizational, and environmental dimensions.

TABLE II. Summary of IoT Implementation Challenges and Mitigation Strategies

Challenge	Description	Proposed Solution	Reference
Cybersecurity Risks	IoT devices vulnerable to hacking and unauthorized access, threatening safety system integrity	Blockchain, end-to-end encryption, multi-factor authentication	[23]
High Initial Cost	Large upfront expenditure on sensors, cloud infrastructure, and legacy system retrofitting	Green IoT devices, modular deployment, long-term ROI planning	[24]
Interoperability	Multi-vendor devices with incompatible protocols preventing seamless communication	Standardization via OPC UA; open-source middleware layers	[5]

Scalability	Network and device strain as plant infrastructure expands	Edge computing nodes; scalable cloud architectures	[8–9]
Data Management	Difficulty extracting actionable insights from massive sensor data volumes	AI/ML-driven analytics platforms with real-time processing	[25]
Workforce Resistance	Employee reluctance due to fear of displacement and skill gaps	Training programs; userfriendly interfaces; smart PPE adoption	[7]
Harsh Environments	Extreme heat, humidity, and vibration degrading IoT device performance	Industrial-grade ruggedized sensors; redundant sensor deployment	[9]

Cybersecurity Risks: IoT systems are interconnected and often vulnerable to hacking, unauthorized access, and data breaches [23]. In power plants, a cyberattack could compromise critical safety mechanisms. Securing IoT networks requires robust encryption, authentication protocols, and firewalls.

High Initial Investment: Deploying IoT systems requires significant upfront investment including sensors, communication networks, cloud infrastructure, and legacy system retrofitting [24]. For smaller or older power plants, these costs may deter adoption despite long-term benefits.

Interoperability and Scalability: Power plants often utilize multi-vendor equipment with incompatible protocols, necessitating custom integrations [5]. As plants expand, scalability of IoT infrastructure becomes a concern, requiring frequent upgrades.

Data Management and Workforce: IoT devices generate massive data volumes [25], and without advanced analytics tools, extracting actionable insights is difficult. Additionally, workforce resistance and skill gaps significantly hinder effective IoT implementation.

B. Future Directions for IoT in Accident Prevention

Despite these challenges, the future of IoT in accident prevention for power plants is promising. Fig. 4 maps each identified challenge to its corresponding future solution, providing a clear roadmap for overcoming barriers.

Fig. 4. Mapping of IoT implementation challenges to corresponding future solutions in power plant safety.

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- Digital Twins: Virtual replicas of physical systems enable operators to test safety protocols, predict failures, and optimize operations without disrupting actual systems.
- AI/ML Integration: Advanced predictive analytics identify complex patterns in IoT data to predict accidents well in advance [26–27], while ML algorithms improve safety protocols by learning from historical data.
- Blockchain: Decentralized, tamper-proof blockchain technology ensures secure data transmission, prevents unauthorized access, and maintains the integrity of safety systems.
- Edge Computing: Local data processing reduces latency and ensures faster response times critical for accident prevention, while alleviating burdens on centralized cloud systems.
- Standardization: OPC UA and similar frameworks aim to ensure seamless communication between devices from different manufacturers, reducing complexity and costs.
- Smart PPE and Autonomous Systems: Smart helmets with AR displays guide workers through safety protocols in hazardous environments [7]. Autonomous drones equipped with IoT sensors can inspect equipment and respond to emergencies, reducing reliance on manual inspections.

Fig. 5 illustrates the broader ecosystem of complementary technologies—including 5G, blockchain, edge computing, robotics, quantum computing, and digital twins—that synergize with IoT to create a comprehensive safety platform.

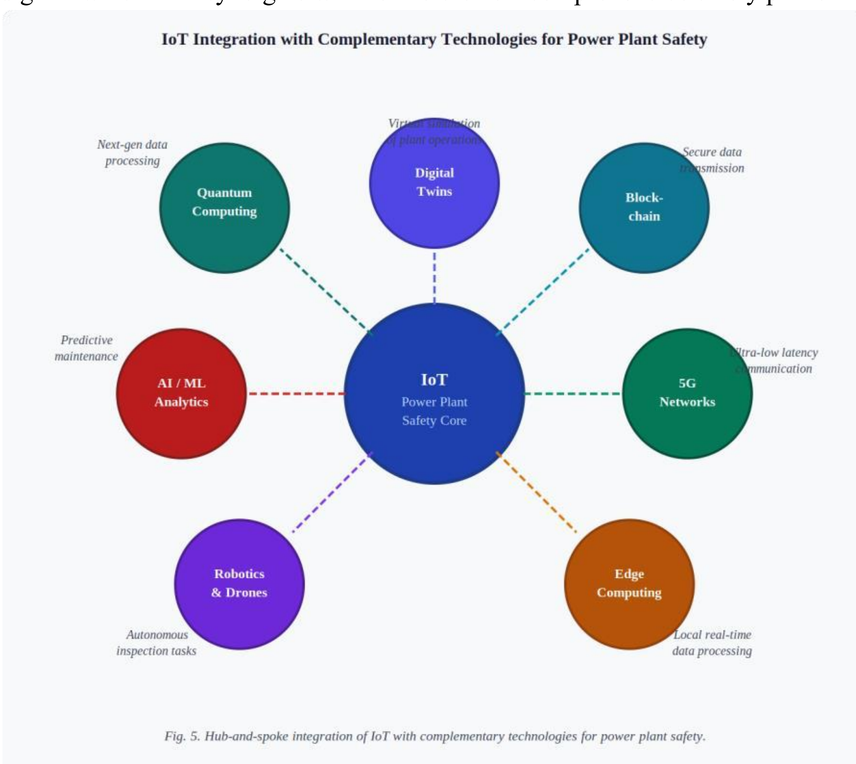

Fig. 5. Hub-and-spoke integration of IoT with complementary technologies for power plant safety

Table III compares the wireless communication protocols most commonly employed in IoT-enabled power plant safety systems, providing a practical guide for system designers.

TABLE III. Comparison of Wireless Communication Protocols for IoT-Enabled Power Plant Safety

Protocol	Range	Data Rate	Power Consumption	Suitability for Power Plants
Zigbee	10–100 m		Very Low	Best for dense sensor

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		250 kbps		networks in confined areas (indoor machinery)
LoRaWAN	2–15 km	0.3–50 kbps	Very Low	Ideal for large outdoor plant areas; long-range low-power monitoring
5G	< 1 km (cell)	Up to 10 Gbps	Moderate–High	Optimal for high-bandwidth real-time video and critical alarms
Wi-Fi (802.11)	30–100 m	Up to 9.6 Gbps	Moderate	Suitable for control rooms and high-data-rate applications
Bluetooth LE	1–100 m	1–2 Mbps	Low	Appropriate for wearable devices and short-range worker monitoring

IV. CONCLUSION

The application of IoT for real-time accident prevention in power plants represents a paradigm shift in industrial safety. By enabling predictive insights and faster response times, IoT minimizes risks and enhances operational efficiency. This paper presented the layered IoT architecture (Fig. 1), the real-time accident prevention workflow (Fig. 2), the wearable device ecosystem (Fig. 3), a structured mapping of challenges to solutions (Fig. 4), and the broader technology integration landscape (Fig. 5). Key sensor types (Table I), implementation challenges with mitigation strategies (Table II), and protocol comparisons (Table III) provide actionable guidance for practitioners. While challenges such as cybersecurity vulnerabilities and high initial costs remain, ongoing advancements in digital twins, blockchain, edge computing, and advanced AI promise to overcome these barriers. As the energy sector continues to embrace digital transformation, IoT stands at the forefront of revolutionizing industrial safety, ensuring a safer future for workers, equipment, and the environment.

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