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ENVIRONMENTAL SAFETY AUDIT IN CONDITIONS OF EMERGENCY SITUATIONS BASED ON ARTIFICIAL INTELLIGENCE AND INTERNET OF THINGS TECHNOLOGIES

Ensuring environmental safety under increasing anthropogenic and natural threats requires highly reliable digital systems capable of continuous monitoring, rapid diagnostics, and timely response to hazardous deviations. The integration of Artificial Intelligence (AI) and Internet of Things (IoT) technologies is becoming a key direction for strengthening the analytical capacity and operational efficiency of environmental safety audit, particularly in emergency scenarios where data volumes, uncertainty, and dynamics significantly intensify. This study provides a systematic examination of contemporary AI and IoT solutions, focusing on their functional properties, constraints, and applicability to enterprise-level environmental assessment. Special attention is given to the specific operational requirements and challenges associated with emergency conditions, where the reliability, adaptability, and automation of decision-making mechanisms are critical. Based on the conducted analysis, a generalized architecture of an integrated environmental safety audit system is proposed. The architecture incorporates a distributed IoT sensor layer for high-resolution data acquisition, intelligent AI-based modules for state evaluation and anomaly detection, and adaptive operational modes ensuring stable system *functionality during transitions from normal to emergency states. The proposed framework is characterized by structural flexibility, scalability, and applicability across diverse industrial domains, enabling improved situational awareness and more accurate environmental risk assessment. The results obtained substantiate the effectiveness of combining AI and IoT for strengthening technological resilience and enhancing the precision of environmental safety audit. The proposed architecture forms a methodological foundation for further research aimed at expanding system autonomy, improving predictive capabilities, and increasing robustness under complex and rapidly evolving risk conditions.*

Keywords: *environmental safety audit, artificial intelligence, Internet of Things, emergency scenarios, industrial monitoring, intelligent decision support, integrated system architecture.*

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АУДИТ ЕКОЛОГІЧНОЇ БЕЗПЕКИ В УМОВАХ НАДЗВИЧАЙНИХ СИТУАЦІЙ НА ОСНОВІ ТЕХНОЛОГІЙ ШТУЧНОГО ІНТЕЛЕКТУ ТА ІНТЕРНЕТУ РЕЧЕЙ

Забезпечення екологічної безпеки в умовах зростаючих антропогенних та природних загроз вимагає високонадійних цифрових систем, здатних виконувати неперервний моніторинг, швидку діагностику та своєчасне реагування на небезпечні відхилення. Інтеграція технологій штучного інтелекту (ШІ) та Інтернету речей (IoT) стає ключовим напрямком для посилення аналітичних можливостей та операційної ефективності аудиту екологічної безпеки, особливо в надзвичайних ситуаціях, коли обсяги даних, невизначеність та динаміка значно зростають. У даному дослідженні представлено систематичний огляд сучасних рішень ШІ та Інтернету речей, зосереджуючись на їх функціональних властивостях, обмеженнях та застосовності до оцінки екологічної безпеки на рівні підприємства. Особлива увага приділяється конкретним операційним вимогам та викликам, пов'язаним з надзвичайними умовами, де надійність, адаптивність та автоматизація механізмів прийняття рішень є критично важливими. На основі проведеного аналізу запропоновано узагальнену архітектуру інтегрованої системи аудиту екологічної безпеки. Архітектура включає розподілений сенсорний шар IoT для збору даних з високою роздільною здатністю, інтелектуальні модулі на основі ШІ для оцінки стану та виявлення аномалій, а також адаптивні режими роботи, що забезпечують стабільну функціональність системи під час переходів від нормального до *надзвичайного стану. Запропонована система характеризується структурною гнучкістю, масштабованістю та застосовністю в різних промислових сферах, що дозволяє покращити ситуаційну обізнаність та точність оцінки екологічних ризиків. Отримані результати підтверджують ефективність поєднання штучного інтелекту та Інтернету речей для посилення технологічної стійкості та підвищення точності аудиту екологічної безпеки. Запропонована архітектура формує методологічну основу для подальших досліджень, спрямованих на розширення автономності системи, покращення прогностичних можливостей та підвищення стійкості у складних та швидкозмінних умовах ризику.*

Ключові слова: *аудит екологічної безпеки, штучний інтелект, Інтернет речей, сценарії надзвичайних ситуацій, промисловий моніторинг, інтелектуальна підтримка рішень, інтегрована системна архітектура.*

Introduction. Environmental safety has become a critical component of sustainable industrial development, particularly in sectors where hazardous materials, high-energy processes, or complex technological infrastructures pose elevated ecological and human health risks (Mazzi, 2023). Ensuring compliance with environmental regulations is no longer sufficient, as the enterprises must maintain continuous oversight of potential environmental hazards to prevent large-scale contamination and ecosystem degradation. The relevance of environmental safety audits is especially pronounced under conditions of technological accidents or emergency situations, where the speed and accuracy of environmental assessment directly influence the scale of damages, recovery time, and risks to surrounding communities (Hao et al., 2022). As global industrial systems become increasingly interconnected and resource-intensive, the demand for robust methodological frameworks capable of ensuring environmental resilience has significantly intensified.

Traditional approaches to environmental safety auditing rely on periodic inspections, manual data collection, static monitoring systems, and standardized checklists aimed at evaluating compliance with environmentally significant operational parameters (Huang et al., 2021). In the context of emergency risk identification, these methods typically involve expert-driven hazard analysis, fault-tree assessments, and instrument-based control of critical indicators such as pollutant emissions, effluent composition, and process deviations. Although these techniques provide a foundational basis for environmental oversight, their effectiveness is constrained by temporal latency, limited adaptability to rapidly evolving operational conditions, and incomplete visibility into complex multi-factor interactions that often precede emergency events. Consequently, conventional audit procedures may fail to detect weak signals of system instability or emerging threats before they escalate into full-scale environmental emergencies.

In recent years, the integration of advanced digital technologies, particularly Artificial Intelligence and Internet of Things architectures, has emerged as a transformative direction for enhancing environmental auditing processes (Olawade et al., 2024). IoT-enabled sensor networks offer high-resolution, real-time measurements of environmental and technological parameters, while AI-driven analytical systems enable early detection of anomalies, predictive assessment of emergency scenarios, and automated interpretation of large-scale heterogeneous datasets. These technologies introduce fundamentally new capabilities, including continuous monitoring, adaptive thresholding, intelligent classification of hazardous states, and generation of data-driven insights that were previously unattainable through classical auditing approaches. Their adoption not only improves audit accuracy and operational speed but also enhances the resilience and responsiveness of enterprise-level environmental management systems.

Given the increasing complexity of industrial operations and the rising frequency of technological incidents worldwide, the development of comprehensive models, advanced methodological frameworks, and integrated technological solutions for environmental safety auditing has become an urgent research priority. Achieving effective and efficient auditing in emergency-prone environments requires the rational combination of IoT-based sensing infrastructures, AI-enabled decision-support mechanisms, and intelligent data-processing architectures capable of functioning under dynamic and uncertain conditions. Therefore, this study focuses on conceptualizing and substantiating modern approaches for the synergistic use of emerging digital technologies in environmental safety auditing, with special emphasis on their application within emergency situations, where rapid situational awareness and intelligent response strategies are essential.

Analysis of recent research and publications. In recent years, the academic community has developed a substantial variety of methods and solutions for monitoring and auditing environmental safety across different industrial sites. Traditional approaches include periodic environmental inspections, fixed point sampling, manual audits, and laboratory analyses of emissions and effluents (Chun et al., 2020). For example, classical environmental auditing on industrial plants often involves gas chromatography to analyze pollutant concentration in stacks, as well as chemical analysis of wastewater to assess compliance with discharge limits (Moretti et al., 2020). These conventional practices remain the backbone of regulatory compliance and provide robust baseline data for environmental performance.

More recently, research has increasingly converged on the integration of Artificial Intelligence and Internet of Things technologies for environmental monitoring and auditing. AI-driven techniques, such as machine learning and deep learning, enable automated anomaly detection, predictive forecasting, and classification of environmental states, while IoT sensor networks facilitate real-time acquisition of heterogeneous environmental parameters (e.g., gas concentrations, temperature, humidity). For instance, there are frameworks that embed edge-AI within IoT nodes to enable on-device inference and energy-efficient continuous monitoring (Wiese et al., 2025, Miller et al., 2025, Rahman et al., 2024). Other work demonstrates how AI-IoT systems can detect greenhouse gas emissions in real time, applying predictive analytics for emissions surveillance (Yavari et al., 2023). In parallel, IoT/AI has been employed for the early detection of environmental emergencies: anomaly detection models based on time-series data from sensors have been used to flag potential leakages or hazardous discharges before they escalate (Bajwa, 2025).

Despite these advances, most of existing solutions remain isolated in their operation: AI-based analytics systems are developed separately from IoT networks, or IoT deployments lack integrated decision support for emergencies. Consequently, the full potential of jointly using AI and IoT in environmental safety auditing, especially under emergency conditions, remains underexploited.

The main aim of this work is to analyze the specific features of AI and IoT technologies and propose a generalized, synergistic framework for their integrated application in enterprise-level environmental safety audits under emergency scenarios.

Presentation of the main research material. The present section provides a systematic exposition of the proposed conceptual approach to enhancing environmental safety audit processes under both normal operational conditions and emergency scenarios. The analysis focuses on the integration of artificial intelligence methodologies, including neural-network–based models and fuzzy-logic systems, into IoT-enabled monitoring infrastructures deployed at industrial enterprises. Particular attention is given to the differentiation between routine audit procedures and emergency-mode assessment, as well as to mechanisms enabling the intelligent transition between these modes.

AI technologies. Artificial intelligence has become an essential analytical tool in modern environmental monitoring due to its capacity to identify complex patterns, infer hidden relationships among multivariate ecological parameters, and support early detection of hazardous conditions (Alotaibi, & Nassif, 2024). Machine-learning algorithms are increasingly applied for forecasting pollutant concentrations, anomaly detection in technological systems, and predictive risk estimation for industrial accidents (Argyroudis et al., 2022). When integrated with sensor-rich IoT infrastructures, AI enables continuous, high-resolution assessment of environmental conditions, providing decision-makers with timely insights into ecological risks and process deviations.

Neural-network methods represent one of the most effective computational paradigms for environmental audit tasks owing to their ability to approximate nonlinear dependencies and learn from large, heterogeneous datasets (Haeri Boroujeni et al., 2024). Convolutional neural networks can be employed for processing image-based environmental data, such as gas-leak visualization or aerial ecological inspections, whereas recurrent and long short-term memory networks are well-suited for analyzing temporal sequences of pollutant concentrations, pressure fluctuations, or emission dynamics. Their application ensures high accuracy in predicting critical environmental indicators, identifying precursor signatures of accidents, and supporting intelligent classification of operational states.

Fuzzy-logic systems, in contrast, provide an interpretable reasoning framework particularly relevant for industrial ecological audits where expert knowledge, linguistic rules, and uncertain measurements must be combined (Congxiang et al., 2024). Fuzzy controllers enable flexible evaluation of environmental conditions based on approximate thresholds, smooth decision boundaries, and adaptive membership functions (Zheng et al., 2025). This makes them especially valuable for scenarios where sensor readings exhibit noise, abrupt fluctuations, or partial incompleteness. Moreover, fuzzy-logic approaches are advantageous in the classification of early emergency indicators, such as borderline pollutant concentrations, irregular pressure gradients, or rapid pH drifts, when rigid deterministic thresholds may lead to false alarms.

Features of environmental safety audit in standard operating modes and in emergency situations. In standard operational mode, the environmental safety audit focuses on systematic assessment of baseline technological processes, verifying compliance with environmental standards, and evaluating trends in key ecological parameters. AI-enhanced audit tools support automated detection of slow-evolving deviations, optimization of filtration or purification cycles, and continuous benchmarking of environmental performance indicators. The system operates with stable thresholds, predictable pollutant emission patterns, and routine verification of the operational state of gas treatment units, wastewater systems, and emission control infrastructure.

Transition into emergency-assessment mode is triggered when the AI-driven decision module detects signatures indicative of a potentially hazardous event. These signatures may include rapid changes in pollutant concentration, abnormal sensor correlation patterns, pressure spikes exceeding model-based predictions, or simultaneous deviations across multiple environmental variables. Neural-network anomaly detectors and fuzzy-rule evaluators may operate separately or in parallel to compute a confidence score reflecting the likelihood of an emergency. When this score surpasses a predefined threshold, the system switches into emergency mode, initiating high-frequency monitoring, activating additional diagnostic routines, and issuing alerts to responsible personnel.

The emergency-mode audit differs fundamentally from routine environmental assessment, as its primary objectives include real-time localization of the hazard source, quantification of immediate ecological risks, and support of rapid operational decision-making. In this mode, AI algorithms prioritize rapid inference over long-term accuracy, enabling the identification of leak intensities, propagation trajectories, and potential environmental impact zones. Fuzzy-logic systems provide interpretable, rule-based reasoning for urgent decision support, while neural-network models assist in predictive estimation of accident escalation dynamics. Together, these technologies facilitate a coordinated, intelligent response to industrial emergencies, ensuring minimal environmental impact and enhanced operational safety.

IoT technologies. The application of Internet of Things technologies plays a foundational role in enabling continuous, high-resolution environmental auditing at industrial enterprises. IoT architectures provide the physical sensing and communication infrastructure upon which modern analytics can operate (Taneja et al., 2024). Distributed networks of smart sensors deployed across critical technological zones allow the system to measure pollutant concentrations, equipment parameters, and environmental conditions with fine temporal granularity. These sensors, equipped with built-in microcontrollers, support preliminary data pre-processing, calibration, and anomaly filtering at the edge, thereby reducing communication overhead and improving the reliability of downstream analytical modules (Maksimov et al., 2025). The resulting sensor ecosystem forms a dense information field that captures both routine operational variations and the earliest manifestations of environmentally hazardous events.

A central advantage of IoT-based monitoring lies in its capability to support real-time data transmission through heterogeneous communication protocols, including LoRaWAN, NB-IoT, Wi-Fi, and industrial Ethernet (Taneja et al., 2024). Such flexibility ensures robust connectivity even under dynamically changing industrial conditions or partial infrastructure failures. Continuous data flow enables analytical models to maintain up-to-date situational awareness and compute predictive indicators of potential emergencies. Furthermore, IoT devices facilitate decentralized data acquisition by integrating multisensory modalities, such as gas concentration meters, pressure transducers, vibration sensors, thermal cameras, and chemical analyzers, into a unified audit framework (Fan et al., 2024). This multimodal integration significantly improves the completeness and accuracy of environmental assessments, allowing the system to detect weakly expressed or composite anomalies that cannot be identified through isolated measurements.

Another important aspect is the interoperability and scalability of IoT infrastructures within enterprise-level environmental audit systems. Modern IoT platforms support standardized data formats, cloud-based storage, and secure communication channels, enabling seamless integration of new sensors, additional monitoring zones, or specialized emergency-detection devices without substantial system redesign. This flexibility is essential for enterprises with evolving production processes or variable environmental risks. Moreover, IoT-driven systems support automated response mechanisms, such as activation of local ventilation, isolation of hazardous zones, or initiation of emergency diagnostics, thereby forming a cyber-physical foundation for intelligent environmental protection.

Integration of AI and IoT technologies. The joint integration of IoT infrastructures with advanced AI methodologies creates a synergistic technological ecosystem that substantially enhances the efficiency, responsiveness, and predictive capabilities of environmental safety audit systems. IoT networks serve as the primary data supply layer, generating continuous, high-resolution streams of multisensory measurements that describe both the operational state of industrial equipment and the surrounding environmental conditions (Popescu et al., 2024). Artificial intelligence algorithms, ranging from deep neural networks to adaptive fuzzy-logic systems, operate as the analytical core, transforming heterogeneous sensor data into actionable insights, early-warning indicators, and context-aware decision recommendations. When combined, these technologies overcome the inherent limitations of traditional audit approaches by enabling dynamic, real-time interpretation of complex environmental variables, detecting subtle precursors of hazardous events, and providing reliable assessments even under uncertainty or incomplete information. The synergy between IoT and AI also supports the construction of hierarchical, self-optimizing monitoring architectures, where local edge-devices conduct preliminary anomaly filtering and AI-powered cloud servers perform high-level pattern recognition and risk forecasting (Kozlov et al., 2024). Such integrated systems not only increase audit accuracy and operational continuity but also facilitate predictive maintenance, automated emergency diagnostics, and intelligent mitigation strategies. Ultimately, the coordinated use of IoT and AI establishes a transformative paradigm for ecological safety audits, shifting them from periodic, reactive procedures to intelligent, continuous, and anticipatory environmental risk management frameworks.

Generalized architecture of the environmental safety audit system in emergency situations. Having analyzed the advantages of AI and IoT technologies, the specific characteristics of their application in environmental safety auditing, as well as the prospects for their combined use we now proceed to formulate a generalized architecture of an environmental audit system designed to operate effectively under emergency conditions.

The generalized architecture of this system, proposed by the authors, is illustrated in Fig. 1, where the corresponding notation is provided: $\boldsymbol{X}_S$ – vector of physical quantities that need to be monitored in the process of environmental audit; $\boldsymbol{U}_S$ – vector of output signals of sensors of the integrated sensor system; $\boldsymbol{U}_{SP}$ – vector of processed signals coming from the local level of environmental safety audit and control; $\boldsymbol{U}_{OS}$< – vector of signals characterizing the state of the system (normal or emergency).

The operation of the proposed generalized environmental safety audit system is organized as a multi-layered framework in which the integrated sensory infrastructure provides the foundational data for both routine and emergency-mode assessments. At the enterprise level, a heterogeneous network of sensors is deployed across technological equipment, engineering structures, and environmentally sensitive zones to monitor the operational integrity of machinery as well as the state of the surrounding industrial environment.

These sensors capture a wide range of critical parameters, including gaseous emissions, temperature, pressure, vibration, chemical composition of water and air, and structural stability indicators, thus forming a comprehensive and continuously updated picture of environmental safety conditions. To support the acquisition and pre-processing of this information, the local audit and ecological control layer incorporates data acquisition modules, local operator stations, communication units, and an alerting subsystem capable of issuing immediate warnings in response to abnormal readings. At predefined time intervals, aggregated data packets are processed locally and then transmitted via the Internet to a remote upper-level audit and monitoring center.

The upper-level subsystem hosts a human-machine interface designed to provide intuitive, high-clarity access for the chief operator and incorporates intelligent analytical modules deployed on a high-performance server infrastructure. The human-machine interface may be accessed from desktop platforms or from a variety of mobile devices equipped with Internet connectivity, thereby ensuring operational flexibility and continuous remote supervision.

Through this interface, the operator can monitor all environmentally significant process

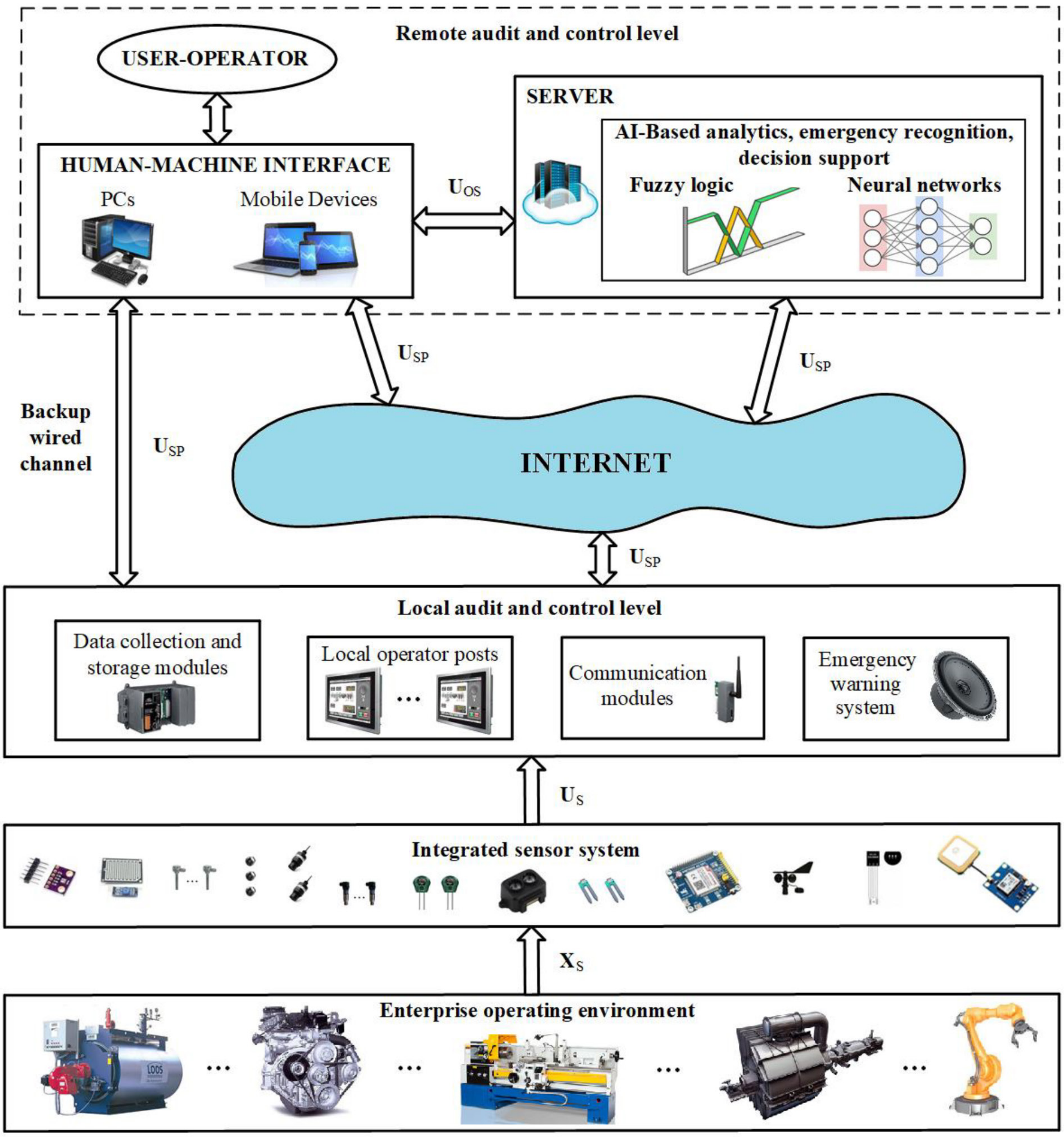

Fig. 1. Generalized functional structure of the environmental safety audit system in emergency situations based on AI and IoT technologies

variables $\boldsymbol{X}_S$ and receive analytical feedback $\boldsymbol{U}_{OS}$ generated by server-side AI modules. These intelligent modules may be implemented using artificial neural networks, trained beforehand on representative datasets containing both normal and emergency-state patterns, or using fuzzy-logic models configured on the basis of expert-derived rule sets. Their functions include the recognition of hazardous conditions and emergency onset, assessment of threat severity and spatial distribution, and the generation of decision-support recommendations for effective and timely response. Based on these insights, the operator is able to make informed managerial decisions that align with the nature, intensity, and dynamics of the detected emergency situation.

To ensure robust functioning even under adverse communication conditions, the system incorporates multiple layers of redundancy. All sensor data are mirrored to local operator stations, enabling autonomous emergency detection and alert activation if connectivity with the remote server is lost. A dedicated autonomous alarm subsystem initiates warning signals automatically when critical thresholds are exceeded, ensuring rapid response independent of network status. In addition to the primary Internet communication channel, the architecture includes an industrial wired backup link, designed to maintain data transmission capabilities in cases of wireless network failure, physical damage to communication modules, or cyber-induced disruptions. Optional short-range radio communication protocols and edge-level AI models can also be integrated to support decentralized emergency diagnostics when both primary and backup communication channels are compromised. Collectively, these features create a resilient and fault-tolerant environmental audit system capable of maintaining operational continuity and high analytical reliability even in the challenging conditions associated with industrial emergencies.

Standard and emergency operating modes of the proposed system. In its standard operating mode, the system functions as a continuous environmental audit and monitoring platform, maintaining steady-state observation of all critical technological and ecological parameters. Measurements are collected at nominal sampling frequencies sufficient for routine diagnostics, compliance verification, and early detection of slow-developing anomalies. Under these conditions, AI-based analytical modules perform low-intensity background assessments, focusing on trend analysis, gradual deviations from normal operating ranges, and detection of early precursors to potential hazards. The goal of this regime is to maintain environmental safety, ensure regulatory conformity, and create a comprehensive historical dataset for subsequent predictive modeling. The local subsystems operate with moderate computational load, and communications are optimized to reduce bandwidth usage while still ensuring timely updates to the remote monitoring level. In this mode, the system behaves as a stable supervisory audit mechanism without unnecessary activation of high-intensity analytical computations or emergency-response protocols.

The transition to the emergency mode is initiated at the moment when the intelligent recognition module detects a combination of sensor signals that correspond to patterns of hazardous states or emerging incidents. Depending on the analytical model in use, this detection may be triggered by neural-network classifiers identifying high-confidence anomaly signatures or by fuzzy-logic inference systems evaluating complex rule sets that describe unsafe parameter combinations. Once the threshold for emergency recognition is exceeded, the system automatically escalates into a high-frequency monitoring state. In this mode, the sampling rates for key sensors, such as those measuring toxic gas concentrations, temperature gradients, pressure surges, or structural vibration, are increased substantially to capture rapid parameter fluctuations typical of emergency dynamics. Additional measurement devices, including portable gas analyzers, mobile robotic platforms, or supplementary thermal sensors, may also be activated to enhance spatial coverage and measurement precision.

During this transition, communication protocols switch to prioritized data streaming, ensuring that the most critical measurements are transmitted with minimal latency to the upper-level monitoring center. The decision-support subsystem concurrently raises its computational intensity, executing rapid predictive assessments, hazard propagation modeling, and real-time risk categorization. At the same time, the system activates specialized alert channels, including local sirens, operator notifications, and emergency messaging to responsible personnel. This emergency-state regime remains active until the system's analytical modules determine that all monitored parameters have returned to stable, safe ranges for a defined period. After stabilization, the system performs a controlled downgrade to the routine auditing mode, while retaining all emergency-related data for further examination, reporting, and improvement of the training datasets or fuzzy-rule bases. Such dual-regime functionality ensures both operational efficiency in normal conditions and rapid, intelligent responsiveness during emergencies, significantly enhancing the overall resilience and effectiveness of environmental safety audit processes.

Limitations and directions for further research. Although the proposed system offers significant advantages for automated environmental safety auditing, it still faces several limitations. First, its overall performance remains highly dependent on the reliability and long-term stability of sensor measurements: drift, fouling, or partial damage of sensors in harsh industrial environments may reduce accuracy and lead to incorrect detection outcomes. Second, AI-based analytical modules require sufficiently large and representative datasets to ensure robust recognition of emergency conditions; however, real-world emergency data are typically scarce, which limits the generalization ability of neural networks and reduces the completeness of expert-defined fuzzy rule sets.

Future research will therefore focus on overcoming these constraints. One promising direction involves developing self-diagnosing and auto-calibrating sensor modules capable of maintaining measurement accuracy under varying operational conditions. Another direction is the synthesis of hybrid analytical models that combine neural networks, fuzzy logic, and synthetic data generation (including simulation-based digital twins) to improve emergency-state recognition even when real datasets are limited. Such developments will enhance the adaptability, robustness, and reliability of next-generation environmental audit systems.

Conclusions. In this work, the stated aim has been achieved by conducting a detailed analysis of the specific features of AI and IoT technologies and by formulating a generalized synergistic framework for their integrated use in enterprise-level environmental safety audits under emergency conditions. The study examined the operational principles, advantages, and constraints of these technologies and outlined their complementary roles in enhancing monitoring accuracy, decision support, and emergency response capabilities.

A focused evaluation of AI techniques, including neural networks and fuzzy-logic models, revealed their strong potential for anomaly detection, predictive assessment, and intelligent decision-making in both routine and emergency audit modes. Likewise, the analysis of IoT infrastructures demonstrated their critical function as the foundational sensing and communication layer, enabling high-resolution data acquisition, real-time information exchange, and continuous situational awareness across industrial environments. The proposed system's generalized architecture, integrating AI-driven analytical modules with an IoT-based sensory network and multi-level control interface, provides a highly effective and universal solution suitable for diverse industrial domains. Its scalability, resilience, and operational adaptability make it appropriate for enterprises with varying technological complexity and environmental risk profiles. Future work will focus on refining sensor reliability, expanding hybrid AI models, and developing advanced simulation tools to further enhance the robustness and predictive capabilities of next-generation environmental audit systems.

Future research will focus on strengthening the system's analytical reliability and operational resilience, particularly through improved data integration mechanisms and more adaptive intelligent models capable of functioning under diverse emergency conditions. It is also planned to consider several specific examples of the application of this system in enterprises.

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