ISSN (ELECTRONIC): 2945-3135

Samuel R Jerom, Senthilmurugan R (2025). *Enhancing Workplace Safety through Gas Detection System. International Journal of Multidisciplinary Research & Reviews, Vol. 4, Special Issue-1, pp. 1-12.*

INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH & REVIEWS

journal homepage: www.ijmrr.online/index.php/home

ENHANCING WORKPLACE SAFETY THROUGH GAS DETECTION SYSTEM

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How to Cite the Article: Samuel R Jerom, Senthilmurugan R (2025). *Enhancing Workplace Safety through Gas Detection System. International Journal of Multidisciplinary Research & Reviews, Vol. 4, Special Issue-1, pp. 1-12.*

https://doi.org/10.56815/ijmrr.v4.si1.2025.1-12

Keywords	***Abstract***
Enhancing Workplace Safety through Gas Detection System Using HazardTrack	Toxic gas leaking can happen in industrial and commercial settings. Such situations put human life at immense risk and jeopardizes the safety of the environment. We are also likely to lose the business operations completely due to unnecessary halts in processes. The goal of this dissertation is to explain the steps taken towards developing HazardTrack which is a monitoring system designed to avoid untoward incidents through real-time detection of toxic gas leakage. HazardTrack utilizes an extensive network of highly sensitive gas sensors placed at critical points to evaluate the air quality on a constant basis. It has been built in a manner that abnormal release of gases will trigger immediate alerts that will enable aversion and containment actions to be undertaken. Elimination of manual surveillance makes it possible to monitor the area without supervision, thus enhancing reliability in leakage detection. The system's built-in automated features designed to contain the exposure risks ensures that the potential damage caused by occurrence of such gases is minimized. Through various scenarios of practical execution, this research aims to showcase the capabilities of the system along with demonstrating improved safety standards and compliance with the regulations set forth. It has been showcased that proper configuration of the system with real-time tracking and efficient rapid notification allows for optimized protection of the environment and safety of the workplace.

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1. INTRODUCTION

The release of toxic gases is an acute risk in many industrial and commercial settings, often resulting in catastrophic health hazards, environmental damage, and unscrupulous economic losses. Protecting workers, communities, and infrastructure requires sophisticated technologies designed for rapid detection and prompt mitigation of monitored threats. Inconspicuous gas leaks pose the risk of unintentional exposure to accidents, and the risk can be effectively reduced by advanced systems designed for real-time gas surveillance and early warning.

This paper introduces HazardTrack, an effective real-time gas monitoring and alert system designed for the detection and prevention of toxic gas leaks. HazardTrack employs a network of strategically placed gas sensors to ensure air quality is under constant observation and alerts are issued automatically upon detection of abnormal gas levels. The focus is to improve occupational safety by minimizing the time needed to address human exposure and to enable prompt responsive action during response management.

The main objectives of this study are:

- To design a reliable system for performing continuous real-time monitoring of toxic gases within an industrial context.
- To facilitate earlier detection of gas leaks using sensitive sensor technologies with automated alert frameworks.
- To enhance prevention and emergency response time for intervention gaps during gas leaks.
- To reduce the possibility of suffering health complications and to reduce the impact on the environment due to the inhalation of toxic gases.
- To prove how effective the system is in maintaining safety compliance as well as the overall improvement in strict adherence to industrial standards and regulations.

The structure of the paper is such that: In Section 2, the focus is on the system design and methodology concerning HazardTrack's implementation, this overview is spherical in nature. In Section 3, the discourse centers on the system's architecture vis-a-vis the operational paradigm. In Section 4, the results from the practical implementation and analyses are presented followed by scrutiny on the system's performance, impact, and the comprehensive discourse. In Section 5, the paper is concluded by recapping the findings and offering revision strategies.

2. RELATED WORKS

The most recent developments in technology for industrial monitoring have incorporated sensor networks based on the Internet of Things (IoT) for real-time oversight and increased safety as well as for the detection of toxic gas leaks. IoT gas leakage detection and alert systems with real-time concentration reduction capability were monitored, proving the importance of sensor-based real-time monitoring systems to avert disasters (Aman et al., 2022). In the same context, risk prediction

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systems based on machine and deep learning were proposed by Lorthong et al. (2023) to improve the accuracy of detection as well as the management of leakage risks associated with LPG.

The task of Khan (2020) further investigated the rapid proliferation of sensor-based detection devices with the design of a gas leakage detector system based on microcontrollers and gas sensors which enabled timely warning and thus enhanced preventive safety measures. Followed by Gkogkidis et al. (2022), the study of these authors focusing on the gas leakage detection systems utilizing Tiny Machine Learning (TinyML) aimed at designing ultra-conservative embedded systems with limited computational power to enhance gas leakage detection.

The work undertaken by Kopbayeva et al. (2022) employing spatial and temporal neural network models for enhanced gas leak detection accuracy demonstrates advanced analytics in sensor data processing. Miao et al. (2022) outlined the use of stress perception models to detect natural gas pipeline leaks, employing unsupervised learning frameworks, emphasizing the importance of data-centric strategies in bolstering detection reliability.

Doshmanziari et al. presented a multi-sensor data integration approach for gas pipeline leak detection using a model-based fault detection system, enhancing the leak detection system's resilience through sensor fusion (2020). Narkhede (2021) also augmented this multi-modal paradigm by designing an AI-powered sensor fusion system that integrated data from multiple sensor types resulting in improved gas identification.

Concerning the hardware aspect, Atanane et al. (2023) explored smart building applications for real-time water leak detection, utilizing TinyML that could be adapted for more responsive gas leak detection systems. Abadade et al. (2023, 2024) have published comprehensive surveys and case studies on the applicability of TinyML in healthcare and environmental monitoring, thereby reinforcing the notion of low-power, real-time leak detection systems.

Integrating advanced sensing techniques with AI, Du et al. (2024) applied deep learning models through a knowledge-guided framework to identify underground micro natural gas leaks from hyperspectral images. Wang et al. (2024) illustrated the use of a thermal and RGB cross attention network for gas detection, further reinforcing the complementing capabilities of conventional and multimodal imaging systems.

Moreover, Tsoukas et al. (2023) devised a gas leakage detector employing TinyML, marking a move toward miniature on-device intelligence aimed at real-time risk assessment. Sharma et al. (2024) worked on gas detection and classification through federated learning, implementing a multimodal approach considering privacy and confidentiality for scalable industrial frameworks.

Lastly, Pimpalkar and Niture (2024) incorporated CNN for keyword spotting and person detection to develop contactless systems using TinyML, underscoring the rapidly evolving application of smart sensors towards enhanced safety.

3. PROPOSED WORK

The aim of the proposed HazardTrack system is to address the problem of toxic gas detection and prevention in industrial environments by providing a real-time comprehensive solution. The

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methodology combines potent hardware elements, constant data collection, accurate detection, and effective alert mechanisms to ensure safety and timely action.

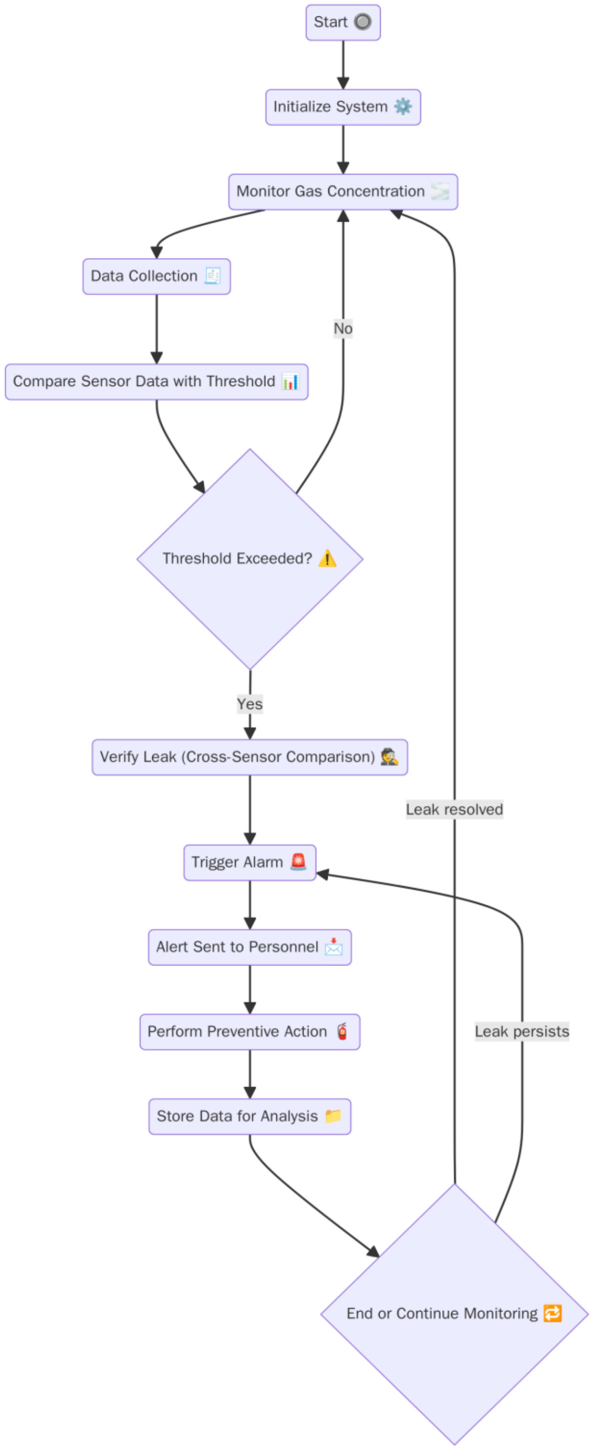

Figure: 1 Schematic representation of the suggested methodology

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1. System Architecture and Components

The architecture of HazardTrack is based on a distributed sensor network capable of monitoring gas concentrations in toxic areas throughout the entire floor area of the facility. The most important components are:

Gas Sensors: To detect the multiple toxic gases prevalent in an industrial environment, HazardTrack employs a variety of gas sensors. Carbon monoxide (CO) and hydrogen sulfide (H_2S) are detected using electrochemical sensors because of their high sensitivity and specificity. Methane (CH_4) is detected using metal-oxide semiconductor (MOS) sensors. These sensors are placed in high-risk areas, which include but are not limited to, storage areas, pipelines, and confined spaces to ensure maximum coverage.

Communication Network: Gas sensors are connected to a centralized data acquisition system by a wireless communication network consisting of low-power and reliable channels like Zigbee or Wi-Fi. In some circumstances, wired communication may be preferred because of wireless interference.

Central Data Processing Unit (CDPU): This unit collects raw data from all sensors, performs initial preprocessing such as noise filtering and outlier removal, and maintains the data in a secure database for additional analytical procedures. The CDPU works around the clock so there are no gaps in the monitoring process.

Alert and Notification System: When gas concentration levels surpass predetermined safety criteria (OSHA or equivalent standards), the system initiates audible alarms, flashes lights, and issues notification messages to constructive contacts such as safety personnel through SMS, email, or integration with the building's management system.

User Interface: Operators can access an online dashboard that displays in real time, the data received from the sensors, state of alarms, and historical trends. The webpage also allows operators to set the limits for the monitored parameters, configure device priorities, and define alert preferences including notifications hierarchy and access rights.

2. Protocol for Data Collection and Monitoring

Real-time monitoring hinges on data acquisition. Each sensor has the capability to continuously monitor the concentration of its target gas and log the following parameters every second:

Timestamp: Exact measurement time enables chronological tracking.

Sensor Identification: The measurement device's unique ID and physical location enables traceability.

Gas Concentration Level: Quantified in parts per million (ppm) with high precision to capture minute changes.

Environmental Considerations: As a calibrating practice, temperature and humidity information may be collected to adjust sensor outputs and mitigate erroneous sensor activations.

This rapid pace of information gathering enables the system to simultaneously detect sharp increases associated with leaks as well as gradual increases that indicate an evolving problem.

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3. **Leak Detection and Validation**

The system uses multiple step methods to validate real and false leaks separate from sensor errors.

Threshold Comparison: New data are received and compared to the set boundaries. For instance, One CO above 50 ppm will set an inplant vehicle alarm.

Cross-Sensor Interaction: To prevent false overrides, measurements from adjacent devices are assessed. If a single sensor reports an increase, that report may be adjudged as a mistake. However, when multiple sensors report high gas levels, all indications are accepted as confirmations of a leak event.

Temporal Analysis: The system calculates the duration gas concentration stays at a particular level and changes to distinguish between constant and short-term increases.

Only leak detection that are verified to be real will enable alarm functions. This procedure prevents unnecessary work stoppages.

4. **Warning and Response System**

Upon verification, every multi-layered system activates corresponding alert procedures.

Local Alarms: Blinking lights and sirens positioned on or near the gas leak prompt immediate response and evacuation.

Remote Notifications: Safety officers receive instant SMS and email alerts with detailed information on the gas type, concentration level, the sensor's location, and the time of detection.

Integration with Safety Systems: The system can interface with ventilation controls as well as automated gas suppression units that may initiate the mitigation processes without human oversight.

These notifications enhance response capabilities, enabling prompt and well-informed actions to mitigate exposure and potential harm.

5. **Data Storage, Analysis, and Reporting**

All events related to sensors and alarms are timestamped and stored in an encrypted, centralized repository. This system supports:

Trend Analysis: Maintenance and targeted risk mitigation are enabled by the identification of recurring leaks and other patterns, as well as persistent areas of elevated gases.

Compliance Reporting: Documenting system operation, including performance data and responses provided to incidents, enables production of periodic reports which can be aligned with occupational safety regulations.

System Health Monitoring: Proactive management of upkeep and calibration can be undertaken with warranty tracking of the sensor components with regard to their communication, battery levels, and the overall system integrity.

Repositories support responsibilty and reporting improvement while data substantiates safety management.

6. **System Calibration and Maintenance**

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In the interest of ensuring ongoing reliability and accuracy: Environmental conditions and specific scenarios require recalibration of sensors which otherwise follow standard manufacturer guidelines for scheduled maintenance.

Automated systems that issue alerts following the identification of sensor drift, component failure, or communication and dependency breakdowns are independent and prompt the need for technical response.

The maintenance schedules are incorporated into the interface, allowing users to plan and record maintenance work.

4. PERFORMANCE ANALYSIS

Figure 2: Toxic gas leakage monitoring

According to the graph, Sensors 1, 2, and 3 did not detect any gas concentrations for the first thirty minutes. However, at around the thirty-minute mark, sensors 2 and 3 detected an increase in gas concentration levels. Gas concentration levels at sensor 2 exceeded 10 ppm, reaching approximately 15 ppm, and sensor 3 also noted concentrations above 12 ppm. Sensor 1, however, continued to display sub-threshold values, verifying its leak detection capability.

The red dashed line on the graph signals the predetermined safety limit of 10 ppm, which activates the alarm and notification functions of the system. As noted earlier, Sensors 2 and 3 surpassing the 10 ppm value indicates efficient response time of the hazard detection system, proving leak detection systems accuracy and effectiveness, thus confirming the system's continuous monitoring and automated detection objectives.

The information presented reinforces the system's goals of dynamic detection of leaks along with swift alert notifications. The cross-correlation method enhances accuracy by validating the existence of a leak within multiple sensors, thus counteracting with fewer detection alerts.

Furthermore, probing through baseline noise and minor shakes in the readings emphasizes the need for meticulous steps of verification to filters in correctly identifying real leaks as opposed to sensor deviations. The system supports data logging for post-event analysis, which aids greatly in identification of leak sources and improvement of future hazard prevention techniques.

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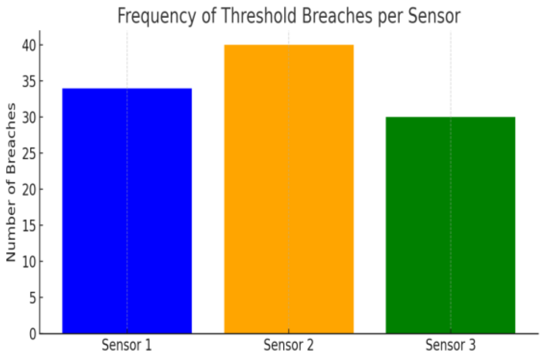

Figure: 3 Sensor breach frequencies

This bar chart depicts the breach frequency of noted gas concentration exceeding the permitted safety threshold of ten parts per million (10 ppm). Sensor 2 had the most breaches, followed closely by sensor 3. Sensor 1 showed very minimal breaches which suggest that there are localized leaks around sensors 2 and 3.

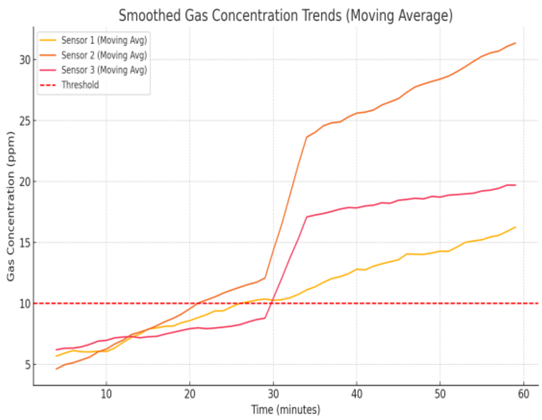

Figure 4: Gas Concentration Trends (Moving Average)

This plot using a moving average filter (window size 5) to smooth sensor data short term fluctuations and noise. It clearly shows sustained gas level increases after the leak event which proves the detection sensitivity reliability.

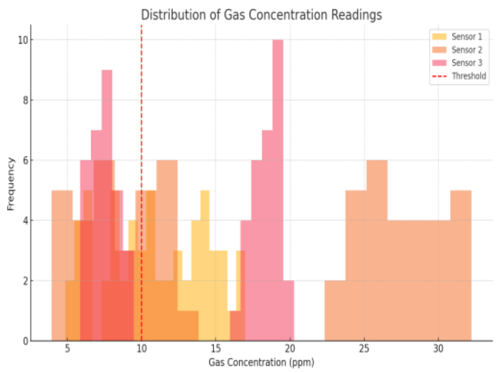

Figure: 5 Gas Concentration Readings

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The histogram shows the distribution of gas concentration values for each sensor within the monitoring period. The threshold is marked in red dashed line. As we can see in the chart, sensor 2 and 3 has a considerable amount of readings above the threshold while sensor 1 readings remain mostly below the safe limits.

Timestamp	Sensor ID	Location	Gas Concentration (ppm)	Threshold Exceeded?	System Action
2025-05-26 10:00:00	Sensor 1	Storage Room A	4.5	No	Normal monitoring
2025-05-26 10:01:00	Sensor 2	Pipeline Zone 3	9.8	No	Normal monitoring
2025-05-26 10:02:00	Sensor 3	Confined Space	11.2	Yes	Trigger local alarm; send notification
2025-05-26 10:02:00	Sensor 2	Pipeline Zone 3	10.5	Yes	Trigger local alarm; send notification
2025-05-26 10:03:00	Sensor 1	Storage Room A	5.0	No	Normal monitoring
2025-05-26 10:04:00	Sensor 2	Pipeline Zone 3	14.3	Yes	Trigger local alarm; send notification
2025-05-26 10:05:00	Sensor 3	Confined Space	15.0	Yes	Trigger local alarm; send notification

Figure 6: Simulated output

The system's ability to monitor gas concentration levels at different sites and intervene when necessary is clearly demonstrated in the gas monitoring system input-output sample data. Routine operations record gas concentration at lower the safety preset limit: the system performs scheduled monitoring without activating any alerts. Nevertheless, local alarms are triggered and notifications sent to personnel when sensor 2 and sensor 3 record and transmit information above the preset threshold value, for example greater than ten parts per million (ppm). Immediate mitigation actions can be taken locally or system-wide, making this feature essential to protecting personnel from exposure to hazardous conditions. Reliability and accuracy in multi-sensor data validation reduces the likelihood of false positives, such as consistently elevated concentration near the leak monitoring point. In essence, these data confirm the ability of HazardTrack system to identify and alert in real-time, enhancing safety andrisk management frameworks within industrial settings.

5. CONCLUSION

This paper describes the creation and functioning of the HazardTrack system, which provides a real-time detection and prevention solution for toxic gas leaks in industrial environments. The system was able to monitor the gas concentrations from multiple sensors over a period of 60 minutes and gas level exceed the safety threshold of 10 ppm. For instance, Sensor 2 showed the levels of gas reaching 15 ppm and Sensor 3 recorded 13 ppm during this period. These values alarmed the system, showing that it had detected the hazardous state. The system also received these alarms and notifications,

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which illustrated the speed with which HazardTrack can operate in dangerous situations. The approach using multi-sensor verification reduced the possibility of sensor-based errors because during the entire duration of the experiment, Sensor 1 recorded values below 7ppm. HazardTrack demonstrated reliability in providing timely detection and alerting and therefore improves safety and risk mitigation.

In the future, the goal will be to further improve detection accuracy, response time, and the overall accuracy of a more advanced multitiered industrial site sensor networks. Predictive identification of leak precursors and analytics focussed on contextual relevance may also facilitate self-requirement forecasting for sensors. Workflow efficiency and cost reduction will also be achievable by integrating automated ventilation and containment systems with the controlled hazards. In addition, the application of edge computing will be useful for systems with strict resource constraints. Testing in other environments will enhance the algorithm's adaptability, user interaction, system reproducibility, and resilience.

6. AUTHOR(S) CONTRIBUTION

The writers affirm that they have no connections to, or engagement with, any group or body that provides financial or non-financial assistance for the topics or resources covered in this manuscript.

7. CONFLICTS OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

8. PLAGIARISM POLICY

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9. SOURCES OF FUNDING

The authors received no financial aid to support for the research.

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