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IoT-Based Continuous Health and Environmental Monitoring System for Drainage Workers Using Wearable Sensors

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Abstract

Drainage workers are routinely exposed to toxic gases, contaminated water, high temperatures, and infectious agents, which can cause severe health risks. This paper presents an IoT-enabled wearable system that enables continuous health and environmental surveillance for drainage personnel. The wearable module integrates physiological sensing— heart rate, SpO_2, skin temperature, and motion (via accelerometer)—with environmental gas detection (H_2S, CH_4, CO, O_2, humidity, and ambient temperature). Data are collected at adjustable intervals, preprocessed on an edge microcontroller, and transmitted through BLE, LoRa, or GSM to a secure cloud platform. The system performs anomaly detection, visualization, and real-time alerting through a mobile and web dashboard. Prototype trials demonstrated reliable 10-second transmission intervals and prompt alerts during simulated exposure and stress scenarios. Edge analytics reduced latency and bandwidth use while maintaining data integrity. Privacy-preserving data handling and configurable alarm policies enhance ethical and operational compliance. The system is scalable for municipal deployment and can be integrated with AI-based risk prediction and GIS localization for optimized emergency response.

Keywords: *Wearable Sensors, IoT, Real Time Health Monitoring, Occupational Safety, Drainage Workers, Gas Detection.*

1. Introduction

Drainage workers represent a vital yet highly vulnerable segment of the urban workforce. Their tasks involve cleaning and maintaining underground sewer lines, inspection chambers, and drainage pipelines that are often filled with toxic gases, contaminated wastewater, and harmful microorganisms. Working in such confined, oxygen-deficient spaces exposes them to a range of occupational hazards including suffocation, chemical poisoning, heat stress, musculoskeletal injuries, and infectious diseases. Hydrogen sulfide (H_2S), methane (CH_4), and carbon monoxide (CO) are the most common gases found in these environments. Even short-term exposure to these gases can lead to dizziness, unconsciousness, or death. Despite the use of protective gear, many workers still face serious health issues due to the lack of continuous surveillance and early warning systems. personal protective equipment (PPE), and periodic medical checkups, provide only limited protection because they lack real-time, continuous monitoring and fail to capture sudden physiological or environmental changes. Traditional safety measures mainly rely on manual gas detectors, periodic air testing, and visual inspections. Supervisors often depend on handheld sensors or the worker's self-awareness to detect danger. However, these methods are intermittent, unreliable, and incapable of identifying sudden environmental or physiological changes. Moreover, drainage workers frequently operate in deep, narrow locations where communication and visibility are limited. Delayed detection of hazardous gas levels or health deterioration often leads to accidents that could have been prevented through real-time monitoring. Therefore, there is an urgent need for a technological solution that can continuously monitor both human health and the surrounding environment and instantly alert supervisors in case of abnormal readings. With recent advances in Internet of Things (IoT), low- power microcontrollers, and wearable sensors, it is now possible to continuously track both environmental parameters and human vital signs simultaneously. Real- time physiological data such as heart rate, oxygen saturation, skin temperature, and activity levels, combined with environmental measurements of gas concentration, humidity, and temperature, can provide early warnings of danger. When integrated with wireless communication and cloud analytics, these systems enable supervisors to monitor workers remotely and respond rapidly during emergencies. The rapid evolution of the Internet of Things (IoT), microelectronic sensors, and wireless communication technologies provides a promising path toward addressing these challenges. Wearable devices equipped with low- power physiological and environmental sensors can track vital health signs such as heart rate, body temperature, and oxygen saturation, while simultaneously detecting the presence of toxic gases and other harmful environmental parameters. These devices can transmit data to a central system through wireless technologies such as Bluetooth Low Energy (BLE), LoRaWAN, or GSM, enabling supervisors to access real-time information remotely. Integration with cloud platforms allows continuous data storage, analysis, and visualization, helping identify trends, predict risks, and enhance safety decision-making. Several recent studies have demonstrated the effectiveness of wearable sensors for healthcare and industrial applications. However, most systems focus on controlled environments like hospitals or offices, where connectivity and maintenance are easier. Drainage worksites present unique challenges: fluctuating temperatures, high humidity, water exposure, signal attenuation, and worker mobility. Therefore, existing solutions are inadequate for this high-risk occupational setting. An effective system must combine rugged design, low power consumption, reliable communication, and edge-level intelligence to ensure uninterrupted operation in harsh conditions. The proposed IoT-based continuous health and environmental monitoring system addresses these specific needs. It integrates physiological sensors (heart rate, SpO_2, skin temperature, and motion detection) with environmental sensors (H_2S, CH_4, CO, O_2, humidity, and ambient temperature) in a compact, wearable module. A microcontroller performs local preprocessing and threshold analysis to issue instant alerts when dangerous conditions are detected. Data are then securely transmitted to a cloud server for storage, visualization, and advanced analysis. The system incorporates data encryption and role-based access to ensure privacy and reliability. By enabling real-time tracking of both the worker's health status and environmental hazards, this system can significantly reduce occupational risks, improve emergency response time, and enhance the overall safety management of drainage operations. It represents a scalable, cost-effective, and practical solution for protecting workers in one of the most hazardous professions and demonstrates how IoT technology can contribute to public health and workplace safety. The challenging and hazardous nature of drainage work demands an advanced safety mechanism that goes beyond traditional manual monitoring. The integration of wearable sensors with IoT technology enables continuous tracking of workers' vital signs and environmental conditions in real time. This approach not only ensures rapid detection of health and gas-related risks but also allows timely alerts to supervisors, minimizing accidents and fatalities. Therefore, this research proposes a wearable IoT-based continuous health and environmental monitoring system specifically designed to enhance the safety and well-being of drainage workers [1-3].

2. Literature Review

Recent work demonstrates that wearable biosensors can continuously record core physiological signals—heart rate, SpO_2, and skin temperature—in ambulatory and harsh environments. These studies focus on improving sensor form-factor and signal fidelity during motion, showing that optical PPG combined with motion compensation algorithms yields reliable heart-rate and oxygen saturation measures. Energy-efficient sampling and adaptive duty cycling extend battery life for all-day operation. Cloud connectivity enables remote supervision and long-term trend analysis. Practical challenges identified include motion artifacts, sweat and humidity effects on optical sensors, and the need for ergonomic mounting to preserve signal quality during strenuous tasks. Another line of research integrates environmental gas sensing with wearable platforms to monitor exposures such as hydrogen

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sulfide, carbon monoxide, and methane. These systems use electrochemical or semiconductor gas sensors in compact packages and focus on rapid detection of hazardous concentration spikes. Work highlights tradeoffs among sensitivity, selectivity, and lifetime in humid, contaminated atmospheres; frequent recalibration and sensor heating or filtering strategies are common recommendations. Studies also emphasize the importance of on-device preprocessing to suppress false alarms and of multimodal fusion—combining gas readings with activity data—to better interpret exposure context and prioritize alerts. Cloud-enabled telehealth architectures for remote monitoring show how time-series databases and analytics pipelines can support real-time alerting and historical audit trails. Prototype implementations demonstrate secure telemetry, configurable thresholds, and mobile dashboards for supervisors. Edge buffering and intermittent upload strategies are used to tolerate connectivity gaps.
Research stresses privacy and access control, recommending encryption in transit, role-based access, and configurable retention policies. Performance evaluations reveal that combining local alerts (vibration/siren) with cloud notifications reduces critical response times in distributed teams, but also that network fallback mechanisms (LoRa/GSM) are necessary where BLE or Wi-Fi signals are unreliable. Reviews on exposure–response monitoring highlight the value of correlating physiological changes with environmental metrics to infer causal links between exposure events and health outcomes. Analytical approaches include thresholding, time-lag correlation, and basic machine learning for anomaly detection. These works indicate that synchronized high-resolution sampling improves detection of short, high-impact exposures but increases power consumption. They recommend hierarchical processing—simple, low-latency rules at the edge and deeper analytics in the cloud—to balance speed and compute cost. Field studies point to sensor drift and environmental confounders as major sources of false positives and underline the need for robust calibration Applied studies deploying wearable monitoring in industrial or municipal pilots report operational lessons: waterproofing, comfortable wear locations, sensor placement, and ruggedized enclosures are critical. Trials often reveal communication blackspots in deep or confined spaces, necessitating multi-modal connectivity and gateway placement strategies. User acceptance hinges on unobtrusiveness and clear benefits—automatic alerts and simple dashboards—plus transparent privacy controls. Technical gaps remain in long-term durability of gas sensors, maintaining calibration in corrosive environments, and scaling analytics for many workers. These pilots conclude that integrated physiological and environmental monitoring is promising but requires systems engineering for real-world resilience [4-7].

3. Proposed System

3.1. Methodology

Building on literature insights, the proposed system fuses continuous physiological monitoring (heart rate, SpO_2, skin/body temperature, and 3-axis accelerometry) with multi-gas environmental sensing (H_2S, CH_4, CO, O_2, VOC/TVOC), humidity, and ambient temperature in a single wearable module. Sensors feed an edge microcontroller that performs motion-compensated preprocessing, drift correction, and lightweight anomaly detection using configurable rules [8-10].

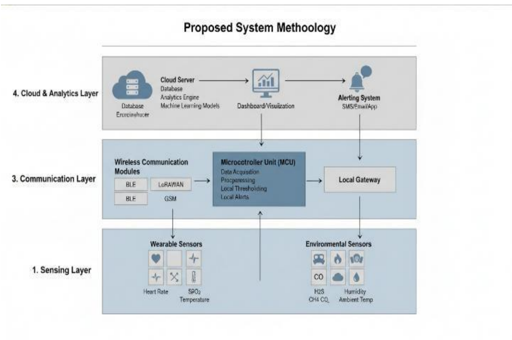

Figure 1 Methodology

Local alerts (haptic/vocal) provide immediate worker feedback while timestamped batches stream via BLE to a nearby gateway; where BLE fails, LoRaWAN or GSM automatically fall back to ensure delivery. The cloud platform ingests time-series data into a secure database, applies thresholding and ML-based risk prediction, and surfaces alerts on a supervisor dashboard and mobile app. Privacy is preserved

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through AES encryption in transit, role-based access, and adjustable data retention policies. The design emphasizes deployability in drainage conditions: waterproof housings, washable straps, and modular gas probes for easy calibration. This integrated approach addresses gaps identified in prior work—real-time paired exposure–physiology visibility, edge preprocessing for low latency, robust multi-network communication, and operational features for municipal scale adoption [11-16].

3.1.1. Existing Methodology

At present, most municipal drainage departments rely on traditional safety practices that are largely manual and reactive rather than continuous and preventive. Workers typically use handheld gas detectors to check for the presence of hazardous gases such as hydrogen sulfide (H_2S), methane (CH_4), and carbon monoxide (CO) before entering a drain or manhole. However, these detectors only provide a momentary reading and cannot monitor changes once the worker begins the task. Health assessment is usually limited to periodic medical checkups or visual supervision, which fail to detect real-time physiological distress such as fatigue, heat stress, or oxygen deficiency. Communication between workers and supervisors is often maintained through two-way radios or mobile phones, which may not function properly underground due to weak signal strength. As a result, emergencies like gas leaks, unconsciousness, or falls are often detected too late for timely rescue. Some organizations have introduced fixed gas sensors or portable alarm systems, but these systems cover only specific areas and do not track individual exposure or vital signs. Moreover, data are rarely logged or analyzed for long-term safety improvement. Environmental changes inside the drainage network can occur rapidly, and without continuous monitoring, workers remain highly vulnerable. Therefore, the existing methods are insufficient for ensuring complete safety in hazardous environments. They lack continuous monitoring, automatic alerts, data integration, and physiological tracking, which are essential for preventing accidents and improving worker health outcomes.

3.1.2. Working

The working principle of the proposed IoT-based health and environmental monitoring system for drainage workers is explained with the help of the flowchart shown in Figure 1 [x]. The system begins once the drainage worker prepares for manhole entry. Before and during entry, the wearable unit continuously collects vital signs such as heart rate, body temperature, SpO_2, and posture information, along with environmental data like gas concentration (H_2S, CH_4, CO, O_2) and ambient humidity/temperature. The monitoring process is carried out in real time using multiple sensors connected to a microcontroller. Data from the sensors are first analyzed at the edge level to verify whether the readings fall within safe operating limits. The microcontroller checks the gas sensor outputs and vital sign parameters periodically. If all readings are within normal ranges, the system confirms a safe condition, and continuous monitoring is maintained throughout the worker's operation. However, if any abnormal situation arises—such as a sudden rise in toxic gas concentration, a fall in oxygen level, irregular heart rate, abnormal body temperature, or a posture change indicating the worker has collapsed—the system immediately activates an alert mechanism. This trigger sends an emergency notification through wireless communication (BLE/LoRa/GSM) to the municipal control center or supervisor. The alert contains details such as the worker's ID, health status, and environmental readings, enabling quick rescue action. Once the alert is sent, the system continues monitoring for further updates or stabilization. This cycle ensures continuous surveillance, faster response times, and improved worker safety during hazardous drainage operations, Figure 2 [17-20].

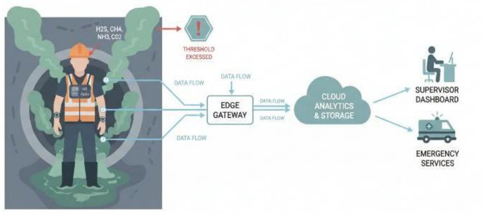

Figure 2 Working

3.1.3. Block Diagram of The Proposed Monitoring System

The block diagram represents the overall working flow of the proposed IoT-based continuous health and environmental monitoring system for drainage workers. The process begins when the system is powered on before the worker enters the manhole. Once the manhole entry stage begins, the wearable device attached to the worker starts recording vital health parameters such as heart rate, oxygen saturation (SpO_2), and body temperature, along with environmental conditions like the concentration of harmful gases (H_2S, CH_4, CO) and oxygen levels. The monitoring of health and environment is carried out continuously through a combination of sensors connected to a microcontroller that processes and compares the readings against safe threshold values. If the measured parameters remain within safe limits, the system detects a safe condition, and the process continues with uninterrupted monitoring. During this time, the worker's posture is also tracked using an accelerometer sensor to ensure normal movement and to detect any signs of fatigue, fall, or unconsciousness. If abnormal posture, high gas concentration, or irregular vital signs are identified, the system classifies the condition as unsafe. In such cases, the system triggers an alert that is automatically sent to the municipal control center or supervisor through a wireless communication module, Figure 3.

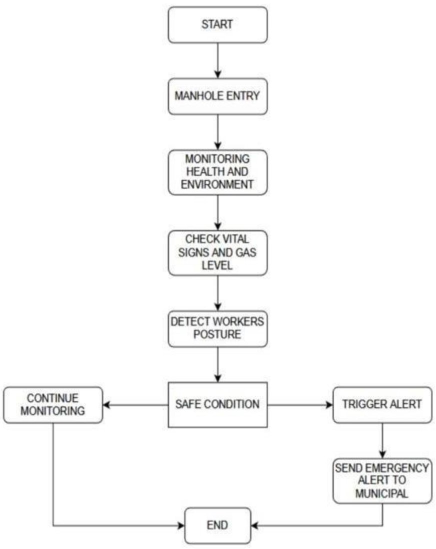

Figure 3 Block Diagram

This alert contains essential details such as worker ID, gas level, and physiological status to ensure immediate rescue or precautionary action. If the conditions remain safe, the monitoring process continues throughout the work period, ensuring constant protection for the worker. The system thus provides real-time safety assurance by integrating continuous sensing, intelligent analysis, and quick alert mechanisms, greatly reducing the risk of accidents in hazardous drainage environments.

Conclusion

The proposed IoT-based continuous health and environmental monitoring system provides an effective solution for ensuring the safety of drainage workers exposed to hazardous environments. By integrating wearable physiological sensors with environmental gas sensors, the system continuously tracks vital signs such as heart rate, SpO_2, and body temperature, along with gas concentrations like H_2S, CH_4, and CO. Real-time data analysis and wireless communication enable instant detection of unsafe conditions and quick alerts to supervisors or municipal authorities. This approach significantly reduces the response time during emergencies, minimizes accidents, and enhances the overall safety management of underground drainage operations. The system's modular design, low power consumption, and cloud-based monitoring make it a scalable and reliable safety tool that can be implemented in various municipal and industrial settings.

Future Scope

The current system can be further enhanced through several technological advancements. Future work may include integrating AI and machine learning algorithms to predict potential health risks or hazardous gas accumulations before they reach critical levels. GPS or GIS-based tracking can be added to locate workers in real time and assist emergency teams during rescue operations. Energy-harvesting modules such as solar or kinetic power can extend battery life, reducing maintenance needs. Additionally, miniaturization of sensors and waterproofing of wearable units can improve comfort and durability in harsh environments. Expanding cloud analytics with historical data visualization can also help municipal authorities identify high-risk zones and plan preventive maintenance. With these enhancements, the proposed system can evolve into a comprehensive, intelligent safety network for protecting workers in hazardous public infrastructure environments.

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