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Hazardsense: An Iot Based Smart Industrial Safety And Security System

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Abstract: Industrial environments require continuous monitoring to ensure the safety of personnel, equipment, and infrastructure. Conventional safety monitoring systems often rely on isolated sensors that display raw values without meaningful interpretation, resulting in delayed response and increased risk during hazardous situations. With the rapid growth of the Internet of Things (IoT), real-time monitoring and automation have become feasible for industrial safety applications. This paper presents *HazardSense*, an IoT-based smart industrial safety and security system designed to monitor multiple environmental parameters such as gas presence, temperature, humidity, light intensity, and flame conditions. The proposed system integrates multiple sensors with an ESP32 microcontroller to collect environmental data and transmit it wirelessly to a centralized dashboard. Threshold-based logic is applied to interpret sensor readings and classify conditions as safe or unsafe. The system provides real-time visualization of environmental conditions, enabling timely alerts and informed decision-making. Experimental evaluation conducted under controlled conditions demonstrates reliable detection of hazardous situations with low response time. The proposed solution is cost-effective, scalable, and suitable for deployment in small- and medium-scale industrial environments, offering an efficient approach to improving industrial safety through smart monitoring.

***Index Terms* -** Industrial Safety, Internet of Things (IoT), Environmental Monitoring, Gas Detection, Smart Systems, Cyber-Physical Security

I. INTRODUCTION

Industrial environments are inherently exposed to a wide range of safety risks due to the presence of hazardous gases, high temperatures, combustible materials, and heavy machinery. Failure to detect unsafe conditions at an early stage can result in serious accidents, loss of human life, equipment damage, and production downtime. Therefore, continuous and reliable monitoring of environmental parameters is a fundamental requirement in modern industrial operations. Conventional industrial safety monitoring systems primarily rely on individual sensors that operate independently and display raw sensor readings. These systems often require manual supervision and expert interpretation, which increases the response time during emergency situations. In addition, such systems lack centralized control and scalability, making them unsuitable for dynamic industrial environments where multiple safety parameters must be monitored simultaneously. With the advancement of the Internet of Things (IoT), it has become possible to design intelligent monitoring systems that collect data from multiple sensors, process it in real time, and provide actionable insights. IoT-based systems enable seamless integration of sensing devices, wireless communication, and data visualization platforms. This allows industries to move from reactive safety measures to proactive safety management. In this context, the proposed HazardSense system aims to provide a smart, low-cost, and scalable solution for industrial safety monitoring. By integrating multiple environmental sensors with an ESP32 microcontroller and a centralized dashboard, HazardSense offers real-time monitoring, interpretation, and visualization of industrial safety conditions.

1 Background and Problem Statement

Industrial safety monitoring has traditionally focused on detecting individual hazards such as gas leakage or temperature rise. These systems are often designed as standalone units with limited interaction between sensors. While such approaches can detect specific hazards, they fail to provide a comprehensive view of the overall safety condition of the environment. Another major limitation of existing systems is the lack of intelligent interpretation. Most systems display raw sensor values without classifying them into meaningful safety states such as "safe" or "unsafe." This places a cognitive burden on operators, who must continuously monitor readings and make decisions under pressure. Additionally, conventional systems are often expensive, complex to install, and difficult to scale. Small- and medium-scale industries may not have the resources to deploy sophisticated safety infrastructures. The absence of centralized visualization further complicates monitoring, especially in environments where multiple parameters need to be observed simultaneously. The core problem addressed in this work is the need for an integrated, affordable, and intelligent industrial safety monitoring system that can continuously observe multiple environmental parameters, interpret safety conditions automatically, and provide real-time visualization and alerts through a centralized platform.

2 Motivation

The motivation for this work arises from the increasing number of industrial accidents caused by delayed detection of hazardous conditions. Small- and medium-scale industries often lack access to advanced safety monitoring solutions due to cost and complexity. With the availability of affordable microcontrollers such as ESP32 and low-cost sensors, it is now possible to design a practical safety monitoring system that is easy to deploy and maintain. The need for a centralized system that provides meaningful interpretation of environmental data and supports timely decision-making motivated the development of the HazardSense system.

3 Proposed Solution

The proposed HazardSense system is designed as a comprehensive industrial safety monitoring solution that integrates sensing, processing, communication, and visualization into a single framework. The system continuously monitors critical environmental parameters that directly impact industrial safety. At the sensing level, multiple sensors are deployed to measure gas presence, temperature, humidity, light intensity, and flame detection. These sensors are interfaced with an ESP32 microcontroller, which acts as the central processing unit of the system. The ESP32 collects sensor data, performs initial processing, and applies threshold-based decision logic Wireless communication enables the transmission of processed data to a centralized dashboard. The dashboard presents real-time graphical representations of sensor values and safety status, allowing operators to quickly identify abnormal conditions. The modular design of the system allows easy expansion by adding additional sensors or functionalities without major changes to the existing setup. The proposed system emphasizes simplicity, affordability, and reliability, making it suitable for deployment in resource-constrained industrial environments.

4 Objective

The main objective of this project is to design and implement a smart hard water softener with automated quality monitoring that ensures consistent and safe water usability while minimizing resource consumption. The system aims to provide real-time monitoring of key parameters such as pH, Total Dissolved Solids (TDS), and mineral concentrations, enabling automated regeneration of the ion-exchange resin based on actual water quality rather than fixed schedules. A microcontroller-based control unit manages system operations, including valve switching and flow regulation, while also supporting predictive maintenance through continuous data logging and analysis. By combining intelligent automation, secure communication, and sustainable operation, the project seeks to deliver an eco-friendly, cost-effective, and scalable water treatment system suitable for households, commercial establishments, and industrial applications, particularly in regions with persistent water hardness.

II. Related Work

Industrial safety monitoring has been an important research area due to the increasing complexity of industrial processes and the rising demand for safer working environments. Traditional industrial safety systems primarily relied on wired sensor networks integrated with Programmable Logic Controllers (PLCs) and Supervisory Control and Data Acquisition (SCADA) systems. These systems were effective for detecting individual hazards such as gas leakage or temperature rise but lacked flexibility, scalability, and remote monitoring capabilities. Moreover, such systems required continuous human supervision and manual interpretation of sensor readings. With the emergence of the Internet of Things (IoT), several researchers have proposed smart monitoring systems that utilize wireless sensors and embedded controllers for real-time data acquisition. IoT-based safety systems enable continuous monitoring of environmental parameters such as gas concentration, temperature, humidity, and flame detection. These systems improve responsiveness and reduce installation costs when compared to traditional wired infrastructures. Many studies demonstrate the effectiveness of IoT platforms in providing remote access and real-time visualization of industrial conditions. However, most existing IoT-based monitoring solutions focus primarily on collecting and displaying raw sensor data. While real-time data availability is beneficial, the absence of meaningful interpretation often places a cognitive burden on operators, who must analyze sensor readings to determine whether conditions are safe or unsafe. In critical industrial environments, such delays can increase the risk of accidents. Recent research efforts have attempted to integrate multiple sensors into centralized monitoring frameworks to provide a more comprehensive view of industrial environments. Multi-sensor systems improve situational awareness by correlating data from different sources. Nevertheless, many of these approaches still lack simple and transparent decision logic, making them difficult to deploy in small- and medium-scale industries due to complexity and cost constraints. Some studies have explored advanced data analytics and intelligent techniques to enhance hazard detection and prediction. While such approaches can improve accuracy, they often require high computational resources, large datasets, and complex training processes. This limits their applicability in low-cost, real-time industrial safety systems. In contrast, the proposed HazardSense system emphasizes simplicity, affordability, and interpretability. By integrating multiple environmental sensors with an ESP32 microcontroller and applying threshold-based logic, the system provides real-time classification of environmental conditions. The centralized dashboard presents interpreted safety information rather than raw data, enabling faster decision-making and improved safety awareness. This approach addresses the limitations of existing systems by offering a practical and scalable solution suitable for real-world industrial environments.

III. Methodology

The methodology of the proposed HazardSense system is designed to ensure continuous and reliable monitoring of industrial environmental conditions through a structured and systematic workflow. The process begins with the deployment of multiple environmental sensors within the industrial environment to measure critical parameters such as gas presence, temperature, humidity, light intensity, and flame detection. These sensors continuously collect real-time data and provide analog or digital signals corresponding to the sensed conditions. The collected sensor data is interfaced with an ESP32 microcontroller, which serves as the central processing unit of the system. The ESP32 reads sensor values at predefined intervals and performs initial preprocessing to ensure stable and consistent readings. Threshold-based decision logic is then applied to the processed sensor data to evaluate the safety condition of the environment. Each parameter is compared against predefined safe limits, allowing the system to classify the environment as either safe or unsafe without the need for human interpretation .Once the sensor data is processed and evaluated, the ESP32 transmits the relevant information wirelessly using Wi-Fi communication to a centralized dashboard. This enables remote monitoring and real-time visualization of environmental conditions. The dashboard displays sensor readings in graphical and numerical formats, allowing users to easily understand current safety levels. When sensor readings exceed predefined thresholds, the system highlights abnormal conditions and triggers alert indications on the dashboard. This methodological approach ensures timely detection of hazardous conditions, reduces reliance on manual supervision, and enhances situational awareness. By combining multi-sensor data acquisition, local processing, wireless communication, and centralized visualization, the HazardSense system provides a practical and efficient methodology for improving industrial safety monitoring.

1 Implementation

The HazardSense system is implemented using an ESP32 microcontroller integrated with multiple environmental sensors, including MQ-2 for gas detection, DHT11 for temperature and humidity monitoring, an LDR for light intensity measurement, and a flame sensor for fire detection. The ESP32 is programmed using the Arduino IDE to continuously read sensor data and apply predefined threshold logic to identify unsafe conditions. Processed sensor readings are transmitted wirelessly via Wi-Fi to a centralized dashboard, where real-time visualization of environmental parameters is provided. The dashboard displays interpreted safety information, enabling quick identification of hazardous situations. The implementation emphasizes simplicity, low cost, and real-time performance, making the system suitable for industrial safety monitoring applications.

FIGURE . 1: Operational workflow of the HazardSense system

2 Tools and Technologies

The HazardSense system is developed using a combination of hardware and software tools to support real-time industrial safety monitoring. The ESP32 microcontroller is used as the core processing unit due to its built-in Wi-Fi capability and low power consumption. Environmental sensing is achieved using MQ-2 gas sensor, DHT11 temperature and humidity sensor, Light Dependent Resistor (LDR), and a flame sensor. The firmware is developed using the Arduino Integrated Development Environment (IDE) with embedded C/C++ programming. Wi-Fi technology is used for wireless data transmission between the ESP32 and the dashboard. The dashboard is developed using web-based visualization tools to display real-time sensor readings and safety status. These tools and technologies collectively enable reliable data acquisition, processing, communication, and visualization for the proposed industrial safety system.

3 System Architecture

The system architecture of the proposed HazardSense solution is designed as a layered IoT-based framework to enable real-time industrial safety monitoring. At the sensing layer, multiple environmental sensors such as gas, temperature, humidity, light intensity, and flame sensors are deployed to continuously monitor surrounding conditions. These sensors are interfaced with an ESP32 microcontroller, which forms the processing layer of the system. The ESP32 collects sensor data, performs basic preprocessing, and evaluates the readings using predefined threshold values to determine safety conditions. The communication layer enables wireless transmission of processed data using Wi-Fi connectivity. Sensor information is sent to a centralized dashboard, which represents the visualization layer of the architecture. The dashboard displays real-time sensor values and safety status in an easy-to-understand format, allowing users to quickly identify hazardous situations. This modular architecture ensures scalability, reliability, and efficient monitoring of industrial environments.

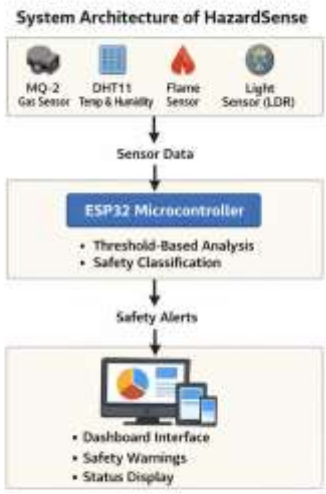


FIGURE 2 : System architecture of the HazardSense system

4 Data Collection and Processing

The HazardSense system collects environmental data using multiple sensors deployed within the industrial environment. Sensors continuously measure parameters such as gas presence, temperature, humidity, light intensity, and flame conditions. The sensed data is acquired by the ESP32 microcontroller at regular intervals and converted into digital values for processing. The ESP32 performs basic preprocessing to ensure stable sensor readings and applies predefined threshold limits to evaluate safety conditions. Each parameter is classified as safe or unsafe based on its measured value. The processed data is then prepared for transmission and sent wirelessly to the centralized dashboard for real-time visualization. This approach ensures accurate data collection, fast processing, and reliable interpretation of industrial safety conditions.

5 Application Integration and Deployment

The HazardSense system is designed for seamless integration into existing industrial environments with minimal configuration requirements. The ESP32-based sensing units are deployed at critical locations to ensure effective monitoring of environmental conditions. Once powered, the system connects to the available Wi-Fi network and begins transmitting processed sensor data to the centralized dashboard application. The dashboard application integrates real-time data from multiple sensing nodes and provides a unified interface for monitoring industrial safety parameters. The system can be deployed in small- and medium-scale industrial setups without the need for complex infrastructure changes. Its modular design allows additional sensors or monitoring units to be integrated easily, enabling scalable deployment based on application requirements.

6 Security Analysis

Operating Security is an important consideration in IoT-based industrial monitoring systems, as sensor data is transmitted wirelessly and may be exposed to unauthorized access or manipulation. In the proposed HazardSense system, basic security measures are incorporated to ensure reliable and safe data communication. The ESP32 microcontroller communicates with the dashboard over a secured Wi-Fi network, reducing the risk of unauthorized external access. Data transmitted from the sensing unit is limited to essential environmental parameters, minimizing exposure of sensitive information. The centralized dashboard restricts access to authorized users, ensuring that only permitted personnel can view monitoring data. Additionally, the use of predefined threshold-based logic at the device level reduces dependency on external processing, thereby limiting attack surfaces. Although the current implementation focuses on basic security mechanisms suitable for small- and medium-scale deployments, the architecture allows future enhancement with advanced security features such as encrypted communication and authentication protocols.

IV. Experiments And Results

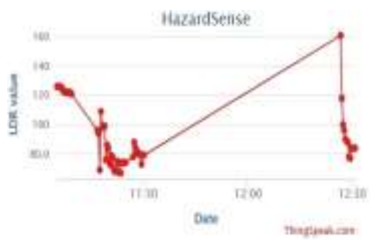
The proposed HazardSense system was evaluated through a set of structured experiments conducted under controlled indoor conditions to simulate real-world industrial environments. The experimental setup consisted of an ESP32-based sensing unit integrated with MQ-2 gas sensor, DHT11 temperature and humidity sensor, LDR sensor, and flame sensor. The objective of the experiments was to verify the system's ability to accurately detect environmental changes, process sensor data in real time, and present interpreted safety information through the dashboard interface. To evaluate gas detection capability, the MQ-2 sensor was exposed to controlled gas sources at varying concentrations. The system successfully detected the presence of gas and classified the air condition as unsafe once the sensor readings crossed predefined threshold values. Corresponding alerts and visual indicators were immediately reflected on the dashboard, demonstrating reliable real-time communication and processing. Temperature and humidity experiments were performed by introducing artificial heat sources and observing ambient environmental changes. The

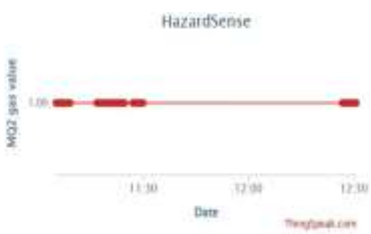
system accurately captured these variations and displayed them as continuous real-time values on the dashboard, enabling clear distinction between normal and abnormal conditions. Light intensity monitoring was tested using the LDR sensor by altering ambient lighting conditions. The system correctly detected changes in illumination levels and updated the dashboard accordingly. Flame detection experiments were carried out by introducing controlled flame sources at safe distances, during which the flame sensor promptly detected the presence of fire-related hazards. These results confirm the responsiveness and reliability of the sensing and processing units. Overall, the experimental results indicate that the HazardSense system is capable of continuously monitoring multiple environmental parameters with minimal response delay. The centralized dashboard provides clear visualization of safety conditions, allowing users to interpret environmental risks efficiently. The successful detection of hazardous conditions across different test scenarios demonstrates the system's practicality and effectiveness for industrial safety monitoring applications.

FIGURE 3 : Dashboard outputs showing temperature , humidity , light intensity and gas detection .

V. Conclusion

This paper presented HazardSense, a centralized IoT-based environmental safety monitoring system designed to interpret multi-sensor data and assess environmental safety conditions in real time. The system integrates commonly used environ- mental sensors, including gas, temperature, humidity, flame, and light





sensors, with an ESP32 microcontroller to provide a unified view of safety conditions within indoor and industrial environments. Unlike conventional monitoring systems that primarily dis- play raw sensor values, HazardSense focuses on interpreting environmental data using threshold-based logic to classify conditions into safe and unsafe states. By converting sensor readings into meaningful safety indicators, the system en- hances situational awareness and reduces the need for continuous manual supervision. The centralized architecture further simplifies monitoring by aggregating multiple environmental parameters into a single platform. Experimental evaluation conducted under controlled conditions demonstrated the system's ability to detect abnormal environmental states and generate timely warnings. The results confirm that multi-sensor integration combined with simple interpetition logic is effective for early warning and preventive safety applications, particularly in resource-constrained environments where low-cost and reliable solutions are required. Future work will focus on extending the system's capabilities by improving gas concentration estimation through additional air quality sensors and calibration techniques. Further enhancements may include long-term data storage, trend analysis, and remote monitoring to support broader deployment scenarios. The modular design of HazardSense allows easy integration of new sensors and functionalities, enabling the system to evolve into a more comprehensive environmental safety monitoring solution

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