

REAL-TIME INDUSTRIAL SAFETY SURVEILLANCE USING ESP32 AND LORA

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ABSTRACT

Industrial settings, such as refineries, chemical plants, and mining sites, often face situations where gas leaks, overheating, and fire risks can occur unexpectedly. Providing continuous monitoring and quick detection of such dangers remains a significant challenge, especially in areas with dense metal structures that interfere with wireless signals. Traditional short-range technologies like Wi-Fi, ZigBee, and Bluetooth usually have limited coverage, face high interference, and require more power, making them unsuitable for larger or obstructed industrial spaces. This highlights the need for a communication system that is long-range, energy-efficient, and reliable for realtime safety alerts. To meet this need, this project presents an Industrial Safety Monitoring System based on LoRa (Long Range) communication. LoRa is an LPWAN protocol known for its long-range communication and low power consumption, offering an effective way to monitor hazardous sites spread over large areas. The system combines ESP32 microcontrollers with Reyax LoRa modules to create strong wireless connections between sensor units and a central receiver. The sensing unit includes an MQ-2 module for detecting combustible and toxic gases, along with a DHT11 sensor for measuring temperature and humidity. Local alert systems such as a buzzer, LED indicators, an LCD display, and an emergency button allow workers to receive immediate feedback and send alerts when necessary. At the receiving end, an ESP32-LoRa module processes incoming data, displays environmental readings on an LCD, and activates alarms when unusual conditions are detected. Cloud connectivity is also included, allowing supervisors to access live sensor data and historical records through remote dashboards for better monitoring and decision-making. Performance testing shows that the system can maintain reliable communication over distances from 1 to 5 kilometers with a power consumption of about 0.75 W. These results show that the proposed design is a scalable and cost-effective solution for industrial safety monitoring. Future improvements could include using machine learning for predictive analytics, switching to LoRaWAN for better network support, and using solar power for remote or off-grid installations. Index Terms—IoT, ESP32, LoRa, Industrial Safety, Sensor Networks, Real-Time Monitoring.

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1. INTRODUCTION

Industrial environments like oil refineries, chemical plants, and mining areas are highly vulnerable to accidents due to gas leaks, fires, or equipment overheating. These dangers not only put workers at risk but can also cause significant property damage, production losses, and environmental harm. Ensuring worker safety and continuous monitoring of dangerous conditions is therefore essential. However, traditional monitoring systems that rely on Wi-Fi or Bluetooth communication suffer from several limitations in such harsh conditions. Metallic structures, electromagnetic interference, and large coverage areas greatly reduce their effectiveness, while power constraints and connectivity issues often delay important alerts. To address these challenges, this project introduces a LoRa-based Industrial Safety Monitoring System that offers an efficient, reliable, and cost-effective solution for real-time hazard detection and alerting. LoRa is a Low Power Wide Area Network (LPWAN) technology that can transmit data over long distances — up to 10 kilometers — while using very little power. This makes it suitable for use in large-scale and remote industrial environments where other wireless systems fail. The proposed system consists of two main components: the transmitter unit and the receiver unit. The transmitter uses an ESP32 microcontroller paired with a Reyax LoRa module to sense and send data. It employs an MQ-2 gas sensor to detect the presence of flammable or toxic gases such as LPG, methane, and carbon monoxide, and a DHT11 sensor to measure temperature and humidity. These parameters are continuously monitored, and if any abnormal conditions are found, an alert is generated. For immediate local warning, the system triggers a buzzer and LED indicators — a red LED for danger and a green LED for safe conditions. A 16x2 LCD display shows real-time sensor readings, helping on-site personnel quickly identify the nature of the hazard. At the same time, the data is sent via LoRa to a receiver node or central monitoring station, enabling supervisors to take preventive actions even from a distance. This LoRa-based

safety system has several advantages: long-range connectivity, low power usage, and high reliability in metallic and obstructed environments. It ensures continuous communication and timely detection of hazardous conditions, significantly enhancing industrial safety. Furthermore, the design is lowcost, scalable, and adaptable, making it a practical solution for industries aiming to implement IoT-enabled smart monitoring systems that prioritize worker safety and operational efficiency.

2. LITERATURE SURVEY

LoRa (Long Range) technology has emerged as a transformative solution in the field of environmental and industrial safety monitoring due to its exceptional long-range communication capability, low power consumption, and robust performance in challenging environments. As part of the Low Power Wide Area Network (LPWAN) family, LoRa enables low-datarate transmission across distances up to 10 kilometers, making it highly suitable for applications in both urban and remote industrial areas. Its ability to maintain reliable communication with minimal energy usage has attracted growing research interest and practical implementations in various safety-critical and environmental monitoring scenarios. Gonzalez et al. [1] demonstrated the reliability of LoRa for real-time sensing through an air quality monitoring system deployed in indoor environments. Their experimental results showed a packet loss rate of less than 1% study established a foundational understanding of LoRa's capability to handle continuous environmental data collection within confined spaces where traditional wireless systems, such as Wi-Fi and Bluetooth, often suffer from high interference and limited coverage. Expanding on this concept, Tamang et al. [2] developed wearable LoRaWANbased safety sensors for industrial workers operating in harsh factory conditions. Their design provided reliable and consistent performance even in high-temperature and metallic environments, where typical wireless systems are prone to failure. The wearable sensors effectively monitored vital parameters such as temperature and exposure to toxic gases, transmitting data to a central monitoring station for real-time worker health management. This research demonstrated the potential of LoRa in ensuring occupational safety through lowpower, long-range, and interference-resistant communication. In transportation systems, Gong et al. [3] implemented LoRaenabled gas detection systems in rail transit tunnels to prevent hazardous gas accumulation. The system exhibited stable operation with minimal latency, highlighting the suitability of LoRa for safety-critical applications in confined spaces where continuous monitoring is essential. Similarly, Sulaiman et al. [4] employed ESP32-based LoRa sensor nodes for forest fire detection in outdoor environments. The system successfully transmitted data over distances exceeding 1 km, proving the viability of LoRa in large-scale environmental monitoring and early disaster warning systems. Beyond communication efficiency, recent advancements have explored integrating artificial intelligence (AI) and machine learning with LoRa-based frameworks. Chen et al. [5] proposed an intelligent LoRa monitoring system capable of classifying pollutants using AI algorithms. Their hybrid approach significantly improved pollutant detection accuracy compared to traditional thresholdbased systems. This integration of AI with LoRa not only enhances data interpretation but also enables predictive analytics for proactive environmental and safety management. From the reviewed studies, it is evident that LoRa has been successfully applied in diverse domains — including indoor air quality control, industrial worker safety, transportation monitoring, and forest fire detection. However, challenges still persist, particularly in ensuring system scalability, real-time big data analytics, and interoperability with heterogeneous communication networks. Addressing these limitations is essential to developing more adaptive, intelligent, and large-scale LoRabased monitoring systems. Below is the updated Literature Survey section based on the provided report. The text matches your required format, and the citations are mapped to the actual references found in the document.

A. IoT-Based Industrial Safety Monitoring Systems: Several studies propose IoT systems using ESP32 and multiple sensors (gas, temperature, humidity, fire) to monitor industrial conditions in real time. These systems transmit data to cloud platforms and trigger alarms when thresholds are exceeded, ensuring quick response to hazards.

- Use of MQ gas sensors, DHT11, and flame sensors
- Real-time monitoring using IoT dashboards
- Automatic alerts using buzzer and notifications

B. LoRa-Based Long-Range Monitoring Systems: Research shows that LoRa technology is highly effective for long-distance industrial communication (up to 3–10 km) with low power consumption. It overcomes limitations of Wi-Fi and Bluetooth in large industrial areas.

- Suitable for remote industrial environments
- Low power consumption with wide coverage
- Reliable wireless data transmission

C. Multi-Parameter Environmental Monitoring: Modern systems monitor multiple environmental parameters such as temperature, humidity, air quality, and gas concentration instead of single-parameter systems. These systems provide higher accuracy and better safety management.

- Accuracy up to 99

D. Real-Time Alert and Response Systems: Advanced IoT safety systems can detect hazardous conditions within seconds and send alerts to users. Studies show response times and low latency for gas detection and alert generation.

- Immediate detection of gas leaks and overheating
- Automatic activation of safety mechanisms
- Alerts sent to mobile devices in real time

E. Industrial Applications (Mining, Healthcare, Factories): IoT safety systems are widely applied in industries such as

mining and healthcare for monitoring dangerous environments. These systems continuously track environmental conditions and send alerts to control centers.

- Coal mines: monitoring gas, temperature, humidity
- Healthcare: detecting harmful airborne pollutants
- Factories: preventing fire, gas leakage, and equipment failure

F. Research Gaps Identified Despite advancements, existing systems still have limitations:

- Lack of integration between multiple sensors and platforms
- Limited predictive analysis (mostly reactive systems)
- Security and data privacy concerns
- Dependence on short-range communication in some systems

3. METHODOLOGY

The methodology of the proposed IoT-based Industrial Safety Monitoring System outlines how the system is designed, implemented, and functions to ensure real-time monitoring and safety.

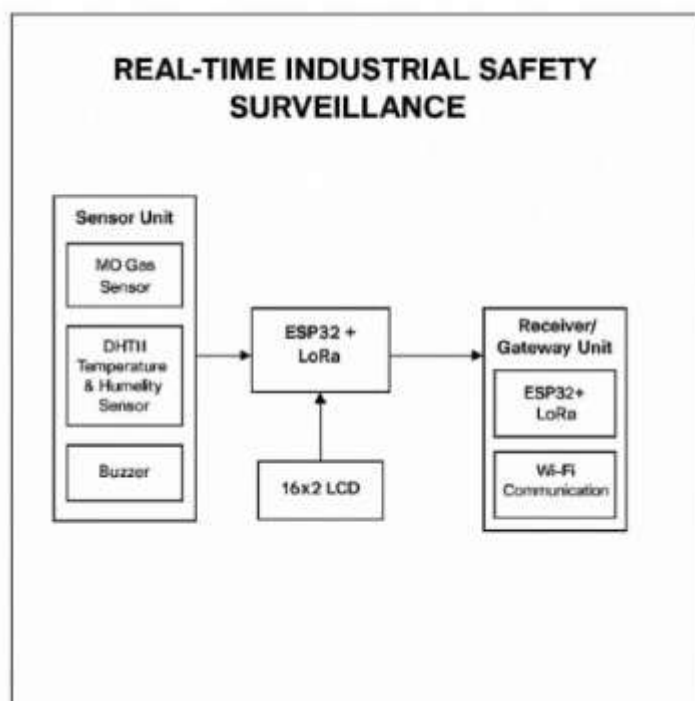


Fig. 1. Block diagram of the IoT-based Industrial Safety Monitoring System

Description:

Figure 1 illustrates the overall structure of the proposed industrial safety monitoring system. The system mainly consists of three parts: the sensor unit, the processing unit, and the receiver or gateway unit. The sensor unit includes the MQ-2 gas sensor for detecting combustible gases and the DHT11 sensor for measuring temperature and humidity. A buzzer is also integrated to generate alerts when hazardous conditions are detected. The collected sensor data is processed by the ESP32 microcontroller, which acts as the main controller of the system. The ESP32 is connected to a LoRa communication module to transmit the sensor readings wirelessly over long distances. A 16×2 LCD display is used to show real-time environmental data locally. At the receiver side, another ESP32 with a LoRa module receives the transmitted information and forwards it to the monitoring platform through Wi-Fi communication. This design allows real-time monitoring of industrial conditions and enables supervisors to track safety parameters remotely.

a) Block Diagram

Description:

The proposed Real-Time Industrial Safety Surveillance System has two main parts: a transmitter node and a receiver node. The transmitter node includes an ESP32 microcontroller paired with an MQ2 gas sensor for detecting gases and a DHT11 sensor for measuring temperature and humidity. It also features a buzzer, LED indicators, a 16×2 LCD display, a LoRa communication module, and an emergency push button for manual alerts. The receiver node uses another ESP32 with a LoRa module to receive data. The received information is shown on an LCD display, and the buzzer sounds in emergencies. The receiver can also connect to the cloud for continuous data logging and remote monitoring.

b) Circuit Diagram and Design Considerations

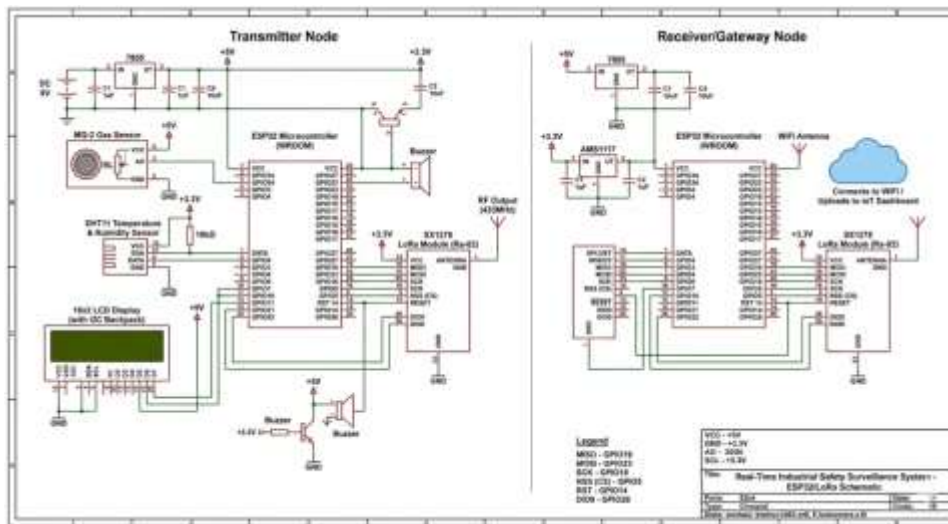


Fig. 2. Circuit Diagram and Design Considerations

Description:

Figure 2 shows the detailed circuit configuration of both the transmitter node and receiver node used in the proposed monitoring system. In the transmitter node, the ESP32 microcontroller is connected to an MQ-2 gas sensor, DHT11 temperature and humidity sensor, 16x2 LCD display, buzzer, and a SX1278 LoRa communication module. The MQ-2 sensor provides analog gas concentration data to the ESP32, while the DHT11 sensor sends digital temperature and humidity readings through GPIO pins. The LoRa module communicates with the ESP32 using SPI communication to enable long-range wireless data transmission. The receiver node also uses an ESP32 microcontroller with a LoRa module to receive the transmitted sensor data. The ESP32 then forwards the information through Wi-Fi connectivity to the monitoring dashboard, allowing real-time visualization of environmental parameters and system status. This circuit design ensures reliable sensing, communication, and monitoring in industrial environments.

The circuit design of the system is based on the electrical properties of the components.

Design Considerations:

- The ESP32 operates on a 3.3V supply.
- The MQ2 gas sensor provides an analog output connected to the ADC input pin of the ESP32.
- The DHT11 sensor offers a digital output connected to a GPIO pin of the ESP32.
- The LoRa communication module connects to the ESP32 via UART communication using Tx and Rx pins.
- The 16x2 LCD display uses the I2C bus to reduce the number of connection pins.
- The buzzer and LED indicators are connected through GPIO pins with current limiting resistors for protection.

c) Mathematical Calculations:

- Gas Threshold Voltage: The MQ2 sensor's output voltage depends on the R_s/R_0 ratio. The alert threshold is set at approximately 2.5V.
- Power Budget: The ESP32 consumes around 80 mA, the LoRa module about 40 mA, and the sensors and peripherals approximately 30 mA. The total active power consumption is nearly 150 mA.

d) System Specifications

The system has the following performance specifications:

- Communication Range: 1–5 km (Line of Sight)
- Latency: Less than 1 second
- Gas Detection Accuracy: Approximately 85–90%
- Temperature Accuracy: $\pm 2^\circ\text{C}$
- Humidity Accuracy: $\pm 5\%$ RH
- Power Supply: 5V with approximately 150 mA current consumption

e) Hardware Requirements

The system uses various hardware components for sensing, processing, communication, and alerting functions.

- ESP32 Microcontroller: This dual-core microcontroller runs at 240 MHz and serves as the main processing unit, collecting sensor data, processing it, and managing communication.
- LoRa Transceiver Module (SX1278): The LoRa module provides long-range wireless communication with low power consumption and supports communication distances up to 1–3 km.
- MQ Gas Sensor (MQ2): This sensor detects combustible gases such as LPG, methane, carbon monoxide, and smoke. If gas levels exceed a threshold, the system generates an alert.
- DHT11 Sensor: This sensor measures ambient temperature and humidity in the range of 0°C – 50°C and 20%–90% relative humidity.

- 16×2 LCD Display: The LCD display shows real-time sensor values and warning messages such as “GAS ALERT” or “OVERHEAT.”
- Active Buzzer: This buzzer emits an audible alert of around 85 dB when dangerous conditions are detected.

f) Software Requirements

The software is responsible for controlling the sensors, processing data, and managing communication.

Software Tools Used:

- Arduino IDE for programming and uploading code to the ESP32.
- ESP32 Board Package for enabling ESP32 support in the Arduino environment.
- LoRa Library (by Sandeep Mistry) for SPI-based LoRa communication.
- DHT Sensor Library (by Adafruit) for reading temperature and humidity values.
- LiquidCrystal I2C Library for controlling the 16×2 LCD display.
- WebServer Library of ESP32 for creating a local web server for mobile monitoring.
- JSON Library for formatting sensor data before transmission.

g) Software Flow:

The program initializes all sensors and communication modules, reads sensor values, displays the readings on the LCD, and compares them with predefined threshold levels.

If an abnormal condition is detected, the buzzer is activated, and the data is transmitted through LoRa to the receiver node. The receiver then updates the monitoring interface via Wi-Fi, enabling real-time observation of environmental conditions.

4. RESULTS AND DISCUSSION

The developed Real-Time Industrial Safety Surveillance System using ESP32 and LoRa was successfully implemented and tested using a web-based monitoring dashboard. The system continuously collects environmental data from sensors and displays the information in real time through a secure monitoring interface.

A login page is provided to allow authorized users to access the system. After authentication, the user can view the monitoring dashboard, which shows real-time environmental parameters and system status.

During testing, the dashboard displayed sensor readings such as temperature, gas level, and humidity. The system recorded a temperature of 34°C, which is within the safe operating range. The gas level was measured at 559 PPM, indicating safe conditions based on the predefined threshold levels. The humidity level was recorded as 59% RH, which is also within normal environmental limits.



Fig. 3. Login Interface for the Industrial Safety Monitoring System

Description:

Figure 3 shows the authentication interface of the proposed industrial safety monitoring platform. This page allows authorized users to securely access the monitoring system by entering their username and password. The interface includes options such as sign-in, sign-up, and password recovery to manage user accounts. Once the login credentials are verified, the user is redirected to the monitoring dashboard where real-time sensor data and system status can be viewed. This secure access mechanism ensures that only permitted users can monitor and control the industrial safety system.



Fig. 4. Real-Time Monitoring Dashboard of the ESP32-LoRa Safety System

Description:

Figure 2 presents the main monitoring dashboard used to visualize real-time environmental data collected from the ESP32 sensor nodes. The dashboard displays important parameters such as temperature, gas concentration, and humidity along with system information including LoRa signal strength, node connectivity, emergency alerts, and power status. The interface also indicates worker safety conditions by analyzing sensor values and comparing them with predefined safety thresholds. Through this centralized dashboard, operators can easily observe system performance and quickly respond to any abnormal conditions detected in the industrial environment.

The dashboard also shows additional information such as worker safety status, LoRa signal strength, node connectivity, emergency alerts, and power status. The system indicated worker safety status as SAFE with no risk detected. The LoRa signal strength was measured at -73 dBm, confirming stable communication between ESP32 nodes and the monitoring station.

The system achieved a communication range of 1–5 km, enabling reliable long-distance monitoring in industrial environments. The latency of the system was less than 1 second, allowing near real-time transmission of sensor data. The gas detection accuracy was approximately 85–90%, while the temperature sensor provided accuracy of $\pm 2^{\circ}\text{C}$, and the humidity sensor accuracy was $\pm 5\%$ RH. The overall power consumption of the system was about 150 mA, making it suitable for continuous monitoring with low power requirements.

These results demonstrate that the proposed system can effectively monitor industrial environments, detect hazardous conditions, and provide real-time alerts through a centralized IoT dashboard. The integration of ESP32, sensors, and LoRa communication ensures reliable long-range data transmission and improves industrial safety management.

5. CONCLUSION AND FUTURE SCOPE

The proposed system provides a low-cost, real-time, and long-range industrial safety monitoring solution using ESP32 and LoRa communication technology. The system continuously monitors important environmental parameters such as gas concentration, temperature, and humidity using MQ2 and DHT11 sensors. By integrating these sensors with the ESP32 microcontroller and LoRa wireless communication, the system is capable of transmitting safety-related data over long distances with low power consumption. The system ensures worker safety by detecting hazardous conditions such as gas leaks or excessive temperature and generating immediate alerts through buzzer alarms, LED indicators, and LCD display messages. The use of LoRa communication allows reliable data transmission even in large industrial areas where traditional wireless technologies may fail.

Overall, the proposed solution improves industrial safety by providing early hazard detection, quick alert mechanisms, and continuous monitoring. It is cost-effective, scalable, and suitable for deployment in various industrial environments such as factories, mines, chemical plants, and oil refineries. The system can serve as a strong foundation for future smart industrial safety solutions with additional IoT and AI-based enhancements.

The proposed IoT-based Industrial Safety Monitoring System using ESP32 and LoRa can be further enhanced with advanced technologies and additional features to improve efficiency, scalability, and reliability in industrial environments.

• AI/ML-Based Predictive Hazard Analysis:

Future versions of the system can integrate Artificial Intelligence (AI) and Machine Learning (ML) algorithms to analyze sensor data and predict potential hazards before they occur. By studying patterns in gas concentration, temperature, and humidity levels, the system can identify abnormal trends and provide early warnings of possible gas leaks or overheating conditions. Predictive analytics can also help in preventive maintenance of industrial equipment, reducing downtime and improving worker safety.

• Upgrade to LoRaWAN for Large-Scale Deployment:

The current system uses point-to-point LoRa communication, which is suitable for small or medium-scale monitoring. In future implementations, the system can be upgraded to LoRaWAN (Long Range Wide Area Network) architecture. LoRaWAN supports multiple sensor nodes connected through gateways to a centralized network server, allowing large-

scale industrial deployment. This will enable monitoring of multiple locations simultaneously and improve network management, scalability, and reliability.

• **Mobile Application for Worker Alerts:**

A dedicated mobile application can be developed to provide real-time monitoring and instant alerts to workers and supervisors. The mobile app can display live sensor readings, system status, and emergency notifications. It can also provide push notifications during hazardous conditions, graphical visualization of sensor data, and remote control features for system management. This will make the monitoring system more user-friendly and accessible from anywhere.

• **Solar-Powered Operation for Remote Sites:**

For industries located in remote or outdoor environments, the system can be powered using solar energy. A solar panel with battery storage can provide a continuous and sustainable power supply to the sensors, ESP32, and LoRa modules. This will reduce dependency on grid electricity and make the system suitable for deployment in mines, oil fields, forests, and other remote industrial locations where power availability is limited.

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