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LoRaWAN-Based Smart Industrial Environment Monitoring System using ESP32, ESP-12E and 433 MHz LoRa Wireless Communication

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Abstract—

Continuous monitoring of environmental conditions in industrial areas is essential for protecting workers and equipment, but manual inspection and wired monitoring systems are slow to react and costly to install. This article presents a low-cost Internet of Things based smart industrial environment monitoring system that uses Long Range (LoRa) wireless communication. The transmitter node is built around an ESP32 microcontroller interfaced with a DHT11 temperature and humidity sensor, an MQ135 air-quality sensor, an SW-420 vibration sensor and an LM393 infrared flame sensor. The readings are packetized and sent over a 433 MHz link by an SX1278 (Ra-02) LoRa module. The receiver node uses an ESP-12E (ESP8266) with a second SX1278 module to receive the packets and host a web-based dashboard that shows live readings, trend charts, link-quality indicators and threshold-based status alerts, with optional buzzer and LED indication. The prototype was tested under normal, flame, vibration and gas-exposure conditions. The dashboard correctly displayed the corresponding normal and alert states, while the logged link quality remained between −55 dBm and −75 dBm received signal strength and 9.8 dB to 10.5 dB signal-to-noise ratio. The system provides an affordable and scalable solution for small and medium industries, laboratories and storage facilities, and can be extended with LoRaWAN gateways, cloud storage, mobile notifications and machine-learning-based anomaly detection.

Keywords— LoRa; ESP32; Industrial Monitoring; Internet of Things; Environmental Sensors; Web Dashboard



I. INTRODUCTION

Industrial safety and environmental monitoring are essential for protecting workers and keeping equipment reliable. Temperature and humidity changes, poor air quality, abnormal machine vibration and fire can harm people, damage assets and interrupt production. In many small and medium industries these conditions are still checked by manual inspection or by wired monitoring installations, which need regular supervision, installation effort and maintenance, and which cannot give an immediate warning when a hazard appears [1]–[3].

The Internet of Things (IoT) allows sensors, microcontrollers and wireless links to collect and exchange data so that industrial parameters can be observed remotely. Among the available wireless technologies, Long Range (LoRa) offers long-distance communication at low power consumption, and LoRaWAN is the network protocol defined for LoRa-based devices and network infrastructure [4]–[6]. Several recent studies have applied LoRa to environmental monitoring, including air-quality, water-quality and hazardous-environment monitoring [2]–[7].

Industrial environments, however, still face a research gap. Traditional methods rely on manual inspection and may not provide real-time information about hazardous conditions, wired systems need complex installation and maintenance, and short-range wireless technologies may not give sufficient coverage. This work addresses the gap with sensor-based real-time monitoring and long-range wireless transmission that needs no wired link between the transmitter and receiver.

The objectives of this study are (1) to develop a smart industrial environment monitoring system using the ESP32, ESP-12E and LoRa communication; (2) to monitor temperature, humidity, air quality, vibration and flame conditions with suitable sensors; (3) to transmit the sensor data wirelessly over long distances using SX1278 LoRa modules; and (4) to display real-time data and threshold-based status on a web dashboard for remote monitoring. Section II reviews related work, Section III describes the methodology, hardware and software, Section IV presents the results and discussion, and Section V gives the conclusion.

II. LITERATURE REVIEW

Research on IoT-based environmental monitoring has grown quickly with the availability of low-power wide-area networks. Table I summarizes the LoRa-based studies used as background for this work, together with the proposed system.

Table I: Summary of Related LoRa-Based Monitoring Studies

Ref.	Application focus	Technology
[1]	Underground mine environmental parameters	LoRa, 868 MHz
[2]	Smart environmental monitoring	LoRa-enabled IoT
[3]	Environmental intelligence platform	LoRa-based IoT
[4]	Water-quality monitoring, rural areas	LoRaWAN IoT
[5]	Low-power air-quality sensor node	LoRa
[6]	Hazardous-environment remote monitoring	LoRa network
[7]	Residential building environment	LoRa
Proposed	**Industrial: temperature, humidity, air quality, vibration, flame**	**LoRa 433 MHz, ESP32/ESP-12E, web dashboard**

Reference [1] reports a real-time LoRa-based monitoring system for underground mines and shows that LoRa can maintain a wireless link in demanding industrial surroundings, but it is focused on mine gases and requires a dedicated multi-sensor design. The studies in [2]–[7] show the usefulness of LoRa for environmental and air-quality sensing, remote monitoring and data visualization. However, most of them concentrate on one application



domain, such as indoor air, water or a single hazardous area, and do not combine temperature, humidity, air quality, vibration and flame detection with a web-based dashboard in one low-cost industrial node. The present work builds on these studies by integrating all five parameters in a single node and presenting them on one dashboard.

III. METHODOLOGY

A. System Architecture

The system has two sections, a transmitter node and a receiver node, connected by a LoRa wireless link, as shown in Figure 1. The transmitter node reads the sensors, forms a data packet and sends it through the SX1278 module. The receiver node receives the packet through a second SX1278 module and passes it to the ESP-12E, which updates the web dashboard.

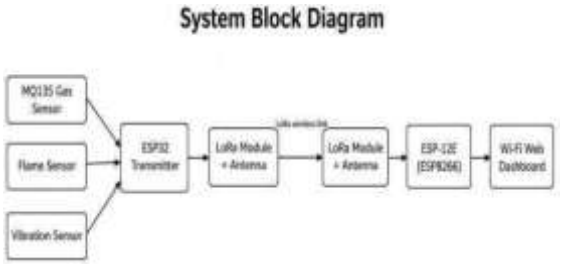


Figure 1: Block diagram of the LoRa-based smart industrial environment monitoring system

B. Transmitter Node

The transmitter is built around an ESP32 development board, a low-cost, low-power microcontroller from Espressif Systems with multiple GPIO pins, analog inputs and communication interfaces. It reads four sensors and sends the data to the LoRa module over the SPI interface. The DHT11 is a digital sensor that measures temperature and relative humidity and is connected to a digital GPIO pin. The MQ135 is a gas sensor used to monitor air-quality changes; its analog output is read by the ESP32 analog input. The SW-420 vibration sensor detects shaking or mechanical disturbance of machinery and gives a digital signal. The LM393 infrared flame sensor module senses the infrared radiation emitted by a flame and provides a digital flame/no-flame output.

C. LoRa Communication Module

Data transfer between the nodes uses the SX1278 (Ra-02) LoRa transceiver operating in the 433 MHz band. LoRa uses chirp spread-spectrum modulation, which provides long-range communication with low power consumption and good interference immunity, and the module is controlled by the microcontroller through SPI. In this prototype the two SX1278 modules form a point-to-point LoRa link with external antennas. The packet carries the temperature, humidity, MQ135 reading, vibration status and flame status.

D. Receiver Node and Alert Devices

The receiver uses an ESP-12E module based on the ESP8266 microcontroller, which provides Wi-Fi and processing capability. It reads the packet from the second SX1278 module and runs a web server. In the prototype the ESP8266 operates as a Wi-Fi access point, and the dashboard is opened from a computer or mobile browser connected to it. An active buzzer module (3.3 V–5 V, digital on/off control) and LED indicators can give audible and visual warnings, for example green for normal operation and red for a warning condition. Table II lists the components and their roles, and Figure 2 shows the hardware modules.

Table II: Hardware Components and Their Roles

Component	Role in the system
ESP32	Transmitter controller; reads sensors and builds packet
DHT11	Temperature and relative humidity
MQ135	Air-quality (gas) sensing, analog
SW-420	Vibration detection, digital
LM393 flame sensor	Infrared flame detection, digital
SX1278 Ra-02 (×2)	433 MHz LoRa transmit and receive link
ESP-12E (ESP8266)	Receiver controller; hosts web dashboard
Buzzer and LEDs	Audible and visual status indication



Figure 2: Hardware components: (a) ESP32, (b) DHT11, (c) LM393 flame sensor, (d) SW-420 vibration sensor, (e) MQ135 gas sensor, (f) ESP-12E, (g) SX1278 Ra-02 LoRa module and (h) indicator LEDs

E. Software and Operating Flow

The embedded software is written in C/C++ using the Arduino IDE and uploaded over USB to the ESP32 transmitter and the ESP-12E receiver. The IDE provides the board packages and the libraries used for sensor interfacing, SX1278 LoRa communication, Wi-Fi connectivity and the web server, and its serial monitor is used to observe readings and debug communication during testing. At the transmitter side the program reads the temperature and humidity from the DHT11, the air-quality value from the MQ135, and the vibration and flame status, and organizes them into a data packet for the SX1278 module. At the receiver side the program extracts the sensor readings and status information from the received packet and serves them through the web server, so that a browser can display the monitored parameters.

The operating flow is shown in Figure 3. After initialization of the ESP32, the sensors, the LoRa modules, the ESP-12E, Wi-Fi and the web server, the system repeats the following cycle: the ESP32 reads the four sensors; the readings are arranged into a data packet; the packet is sent through the SX1278 module at 433 MHz; the receiver SX1278 captures the packet and passes it to the ESP-12E; the ESP-12E updates the dashboard; and the values are compared with predefined thresholds. If a value is abnormal, a warning is shown and the buzzer and LED are activated where available; otherwise the cycle repeats.

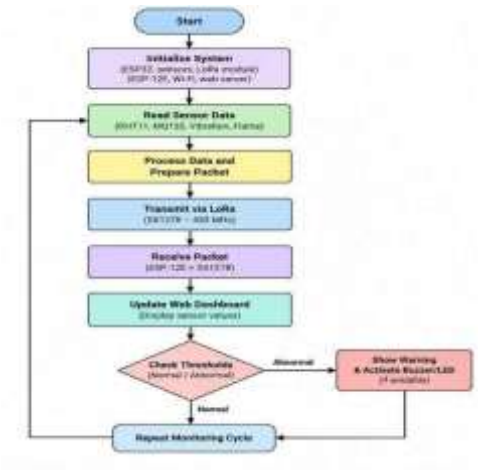


Figure 3: Flowchart of the LoRa-based smart industrial environment monitoring system

F. Threshold-Based Status

The receiver compares the received values with predefined threshold limits to identify excessive temperature, poor air quality, unexpected vibration or flame detection. The dashboard then shows either an “All sensors normal” banner or an alert banner that names the abnormal condition (for example “ALERT: FLAME” or “ALERT: VIBRATION”). Because the flame and vibration sensors give digital outputs, their status is reported as Normal or Detected, while temperature, humidity and the raw MQ135 value are shown numerically with trend charts.

G. Prototype Implementation

The transmitter and receiver circuits were assembled on perforated boards, as shown in Figure 4. The transmitter board carries the ESP32, the DHT11, MQ135, vibration and flame sensors and the SX1278 module, and the receiver board carries the second SX1278 module and the ESP-12E with status LEDs. Each LoRa module is connected to an external antenna. Table III summarizes the main specifications of the prototype.



Figure 4: Prototype of the system: transmitter section (top) and receiver section (bottom) with antennas

Table III: Summary of the Prototype Specifications

Item	Specification
Transmitter controller	ESP32 development board
Receiver controller	ESP-12E (ESP8266) module
LoRa transceiver	SX1278 Ra-02, one per node
Operating frequency	433 MHz
Parameters monitored	Temperature, humidity, air quality, vibration, flame
Sensors	DHT11, MQ135, SW-420, LM393 flame
Dashboard access	Web browser via ESP8266 Wi-Fi
Link indicators	RSSI, SNR, packet counter
Alerts	Dashboard banners; buzzer and LEDs
Programming	C/C++ using the Arduino IDE

IV. RESULTS AND DISCUSSION

A. Dashboard Output Under Different Conditions

The prototype was tested under four conditions: normal operation, flame exposure, vibration and gas exposure to the MQ135 sensor. The dashboard of the ESP-12E receiver, shown in Figures 5 and 6, displays temperature, humidity, vibration status, flame status, the raw MQ135 value and the LoRa signal strength, together with a packet counter, the signal-to-noise ratio (SNR) and the time since the last update. Table IV lists the values observed on the dashboard in each test.



Figure 5: Real-time dashboard output: (a) normal condition and (b) flame detected



Figure 6: Real-time dashboard output: (c) vibration detected and (d) MQ135 gas sensor response

Table IV: Dashboard Readings Observed in the Test Conditions

Parameter	(a) Normal	(b) Flame	(c) Vibration	(d) Gas
Temp. (°C)	38.0	31.3	27.8	27.8
Humidity (%)	29.0	40.3	62.2	58.6



Parameter	(a) Normal	(b) Flame	(c) Vibration	(d) Gas
Vibration	Normal	Normal	DETECTED	Normal
Flame	Normal	DETECTED	Normal	Normal
MQ135 (raw)	0	0	0	528
RSSI (dBm)	−62	−55	−75	−58
SNR (dB)	10.5	9.8	9.8	9.8

B. Discussion

In the normal condition the dashboard showed the "All sensors normal" status with the vibration and flame sensors at Normal and an MQ135 raw value of 0. When a flame was brought near the flame sensor, the flame status changed to DETECTED and the dashboard raised the "ALERT: FLAME" banner; the flame trace in the digital-sensor chart rose to its high level. In the vibration test the vibration status changed to DETECTED and "ALERT: VIBRATION" was displayed, with the vibration trace going high in the chart. In the gas test the MQ135 trace fluctuated strongly, from a raw value of 0 to several thousand counts, which shows that the air-quality sensor responds to changes in the surrounding air. Temperature and humidity were displayed continuously with trend lines in all tests.

The link-quality indicators logged by the receiver stayed between −55 dBm and −75 dBm RSSI and between 9.8 dB and 10.5 dB SNR across the tests, and the packet counter increased continuously (packets 21, 110, 276 and 321 in the displayed screenshots), which indicates that the transmitter–receiver link delivered the sensor data to the dashboard during operation. The update delay shown on the dashboard was below about five seconds in the captured screens. These results confirm that all five monitored parameters can be acquired by one ESP32 node, transmitted over LoRa, and presented in real time with threshold-based status messages.

C. Advantages and Applications

The proposed system offers real-time monitoring of temperature, humidity, air quality, vibration and flame conditions; long-range communication with low power consumption; integration of several sensors in one system; a cost-effective design using affordable microcontrollers, sensors and communication modules; reduced dependence on manual inspection; and easy visualization of readings and status indicators on the dashboard.

The system can be applied in manufacturing industries to monitor temperature, humidity, air quality and vibration in production areas, and in industrial safety monitoring to identify hazardous conditions early. In warehouses, storage facilities and industrial storage rooms it helps protect stored materials by observing temperature and humidity. The vibration sensor supports the detection of unusual machine operating conditions, the flame sensor supports fire-hazard detection in workplaces and storage areas, and the MQ135 sensor supports air-quality monitoring in factories, workshops and laboratories. Further uses include chemical industries, smart factories, research laboratories and remote industrial locations where wired communication is difficult or expensive.

D. Limitations

The accuracy of the measurements depends on the quality and calibration of the sensors. The MQ135 needs proper calibration and is affected by temperature, humidity and other gases, so it indicates changes in air quality rather than the concentration of one specific gas. The DHT11 is a low-cost sensor with limited accuracy. The LoRa communication range is affected by buildings, walls, obstacles, interference and antenna placement, and the range of the prototype has not yet been characterized quantitatively in an industrial site. Remote access to the dashboard depends on the Wi-Fi configuration of the receiver. The flame sensor can fail to detect a fire under some conditions and must not replace certified industrial fire-safety systems. Detection is threshold-based and cannot identify every possible hazard. The prototype uses a point-to-point LoRa link between two SX1278 modules and does not yet include a LoRaWAN



gateway or network server, and the 433 MHz operating band must be checked against the applicable regulations of the deployment country.

V. CONCLUSION

A low-cost smart industrial environment monitoring system based on LoRa wireless communication was designed, built and tested. An ESP32 transmitter with DHT11, MQ135, SW-420 and LM393 flame sensors sends temperature, humidity, air-quality, vibration and flame data over a 433 MHz SX1278 link to an ESP-12E receiver, which serves a web dashboard with live values, trend charts, link-quality indicators and threshold-based alerts. The dashboard displayed the correct normal and alert states in all tests while the link remained stable. The system reduces the need for wired communication and manual inspection and offers an affordable solution for workshops, manufacturing units, warehouses, laboratories and storage rooms.

Future work includes quantitative range and accuracy testing against reference instruments, sensor calibration, integration with a LoRaWAN gateway and network server, cloud storage and historical data analysis, mobile notifications, automated alarms and control, and machine-learning-based anomaly detection to support predictive maintenance.

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