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Multi-Sensor Standalone LoRa System for Early Disaster Prediction

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Abstract: In this paper, a self-contained multi-sensor disaster monitoring system consisting of an ESP32 (transmitter) and ESP8266 (receiver) with LoRa SX1278 modules (433 MHz) was implemented to monitor the disaster. The system incorporates flame, temperature, gas (MQ-2), LDR, and rain sensors in order to detect risky conditions within the environment such as fire, gas leakage, overheating and rainfall. The sensor data is digested on pre-defined thresholds and sent in form of structured packets via long range LoRa communication. It has a real-time representation displayed on the receiver, and a buzzer activated when the conditions inside the system are abnormal which means that the system is not dependent on Wi-Fi, GSM and cloud infrastructure and can be used in remote and disaster-proof regions. Experimental findings proof show clear communication with distances of up to 10km, response time-3 to 4 seconds and high detection. The suggested system offers an inexpensive, low energy consuming, and scalable option of early detection of disasters.

Keywords: LoRa Module (SX1278), ESP32, ESP8266, Disaster Monitoring, Multi-Sensor System, Flame Detection, Sensors, Temperature Monitoring, Gas Sensor (MQ 2), LDR Sensor, Rain Sensor, Long-Range Wireless Communication, Antenna, Standalone System, Early Alert System, Safety Monitoring.

I. INTRODUCTION

Accidents can be avoided by prompt early warning of dangerous incidents so that life and property are minimally lost. Traditional surveillance methods are very much dependent on external communication networks like Wi-Fi, GSM and internet based networks that are usually not effective in emergencies or in remote areas. Thus, a dependable, independent, and stable long vision monitoring scheme, which will not require such infrastructure, is needed. The LoRa (Long Range Radio) technology is the most effective because of its ability to cover a long distance, low power consumption, and work in a license-free frequency range. The SX1278 LoRa board with 433MHz has better signal penetration and diffraction and has a robust communication in obstructed environments. The solution is a two-node disaster tracking system that is proposed to be an independent unit. The ESP32 transmitter measures the various sensors of flame, gas, temperature, rain, and LDR sensors and handles them through programmed thresholds and sends them through LoRa. The receiver, ESP8266 based, uses the data to show the data and the alerts in case of some abnormal conditions detected. It does not need an internet connection, SIM cards, Wi-Fi routers, or LoRaWAN gateways and can, therefore, be used in rural areas, forests, factories, and disaster-prone areas. The goal is to come up with a cost-effective, scalable and reliable development of early hazard detection and fast response solution.

II. LITERATURE REVIEW

The paper by Twahirwa et al. suggested a LoRa-based Internet of Things (IoT)-based air quality monitoring model that can be used in smart cities. The system incorporates inexpensive sensors to track the environmental conditions, including the concentration of CO 2 and the concentration of particulate matter (PM2.5) and transmit the obtained data via LoRaWAN to a central gateway. Visualization of the information is performed using dashboards flowed into the cloud platform where the information is sent by the gateway to perform real-time monitoring and analyze the past. The paper has shown that LoRa communication offers a high practicality in the reliable long-distance transmissions with a low consumption of the power, which is suitable in the systems of monitoring the environment in the urban environment [1].

Abd Rahman et al. examined the propagation and of the link performance of the LoRa communication when used in remote weather monitoring equipment. The study examined the signal strength, range of communication, and environment interference of remote sensor nodes and LoRa gateways. As those results showed, the LoRa technology can be used to assure stable long-range communication even in rural locations with less developed infrastructure. The paper demonstrates the practicality of applying the LoRa gateways to gather the weather information provided by the distributed monitoring stations [2].

The work by Gunti et al. proposed an environmental monitoring system using the LoRa in order to enhance the conventional weather monitoring methods. Many sensors are proposed to be used in the given system in order to estimate parameters defining environmental conditions, including temperature, humidity, and atmospheric conditions. These sensors are attached to a microcontroller processing the data and sending it via LoRa modules to a remote monitoring station. The system focuses on low power, significant coverage, and a reliable wireless communication system. According to the results of the experiment, it is possible to mention that LoRa technology has an important positive influence on the efficiency of the weather monitoring system because it helps to achieve long-range communicative interactivity, as well as experience real-time data gathering [3].

Nyabel et al. established and developed a sensor node based on LoRa and a modest cost in environmental monitoring on developing territories like Uganda. The primary goal of the study was to develop a low-cost and energy-efficient sensory platform, which would be able to obtain data of the environment at regions with minimal technological facilities. The proposed sensor node comprises environmental sensors, a microcontroller and a LoRa communication module which will send data to a central gateway. The authors have shown that the built system is capable of working under the minimal power consumption without losing the ability to communicate reliably at a long distance. This study mentions the significance of environmental monitoring grounded on IoT solutions that are cheap and friendly towards a sustainable environment [4].

Chara et al. carried out the performance analysis of Received Signal Strength Indicator (RSSI) on the internet of things (IoT)-based weather monitoring station, based on LoRa communication. It is an indoor setting study especially in the agricultural industry where sensor nodes can be installed within premises or warehouses. The authors explored the effects of signal strength and distance, obstacles, and the environment. They find out that RSSI and signal-to-noise ratio are significant factors in the establishment of communication reliability between LoRa nodes and gateways. The results are also useful in the design and deployment of sensor nodes in IoT-based monitoring systems to achieve the best communication performance [5].

Munasinghe et al. introduced FireWatch which is a wild fire detection and alert system based on the LoRa and aimed on detecting the presence of a forest fire in its early stages. With the system, parameters like temperature, humidity and smoke levels have been measured in forest areas with the help of environmental sensors. The data gathered is sent through the use of LoRa communication to a main monitoring station where abnormal values create automatic alerts. The system will focus on the early identification of wildfires to minimize the destruction of the environment and enhance disaster response. LoRa will be utilized to achieve low-power consumption and long-range communications with long distance making the technology applicable in remote forest areas [6].

Zhang et al. have introduced a long-range environmental monitoring system through the use of low-power IoT communication, including LoRa. The system has various sensor nodes, which are installed on extensive geographical zones to gather environmental information such as temperature, humidity among other atmospheric factors. Data sent out of such nodes is sent to a gateway hub via the LoRa system and sent to cloud servers to be analyzed and visualized. The system proposed is efficient and shows long distance communications, minimum energy consumptions, and sustainability of data transfer. This study establishes that LORAWAN technologies are very appropriate where one intends to carry out mass monitoring of the environment [7].

III. METHODOLOGY

The suggested system will be capable of continuously measuring environmental parameters like flame intensity, temperature, gas concentration, rain detection and light surrounding in the ambient and sending real-time hazard alerts via a standalone ESP32 SX1278 to ESP8266 architecture. Wi-Fi, GSM, and cloud server independence are eradicated in the design, making it consistently stable in remote areas with a high probability of disasters or where there is a constraint on infrastructure. The figure 1 depicts the block diagram of the entire system architecture.

A. System Overview and Architecture

The architecture of the system is two microcontrollers: ESP32 will be used as a transmitter, and ESP8266 will serve as the receiver and the processing unit of alerts. The ESP32 has several sensors connected to it in both analog and digital gauges:

- Flame Sensor- detects the presence of fire.
- MQ-2 Gas Sensor – used in detecting combustible gases, including LPG, methane, hydrogen, and smoke. Temperature Sensor (DHT22) - uses to read the ambient temperature.
- LDR Sensor - measures the changes in the intensity of the light.
- Rain Sensor- this device senses rain based on change in conductivity of the surface.

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The data is gathered in the form of sensors and constantly compared against predefined numbers and sent out through the SX1278 LoRa module through the use of the SPI. The LoRa module is based on low power communication over a long distance, operating at 433 MHz.

The data is received at the receiver side using the ES8266 together with SX1278 module and shown in real time. If the sensor values pass above threshold limits, a sounder alerts a person on possible dangers. Each of the two nodes is fed with regulated 5V and 3.3V.

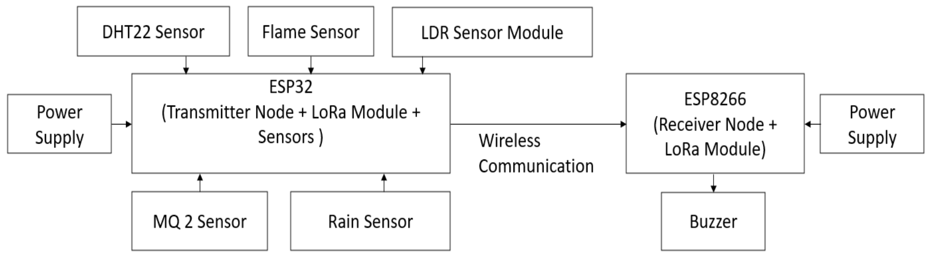

Fig.1. System Architecture

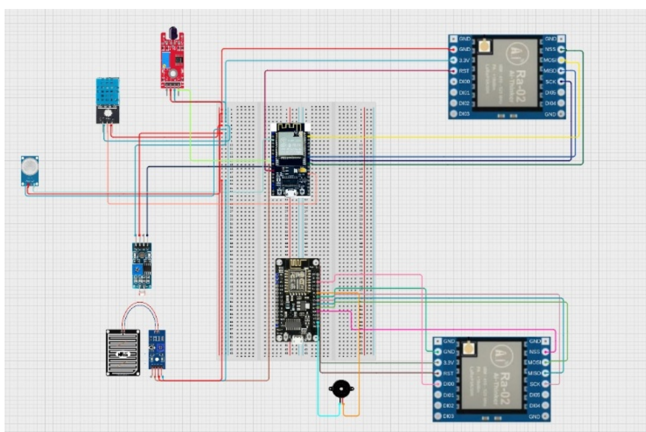

Fig. 2. Circuit Diagram

B. Working Principle

The ESP8266 receives sensor readings with a set time and compares the temperature, gas level, light intensity, flame status and rain status with predetermined values. When there are normal conditions, limits are kept within safe parameters with any deviation being viewed as a possible hazard. In order to minimize false alarms, abnormal conditions are pointed out with the help of several readings. When the ESP32 has been validated, it gathers the most recent sensor data and packages it into a structured data packet with:

Real-time temperature value
• Gas concentration level
• Flame sensor status
• LDR status
• Rain detection status
• Timestamp of the event

The structured data packet is transmitted using the Semtech SX1278 LoRa transceiver, enabling long-range communication with low power consumption. Reliable data transmission is ensured through acknowledgement and retransmission mechanisms, which improve communication robustness. At the receiver side, the Espressif ESP8266 receives the incoming data, displays it, and triggers alerts such as buzzer activation based on the severity of detected events. The system also performs basic edge-level analysis, including trend monitoring and anomaly confirmation, which enhances detection accuracy. Additionally, adaptive sampling increases the data sampling rate during abnormal conditions for improved responsiveness.

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The architecture supports scalability by allowing multiple sensor nodes to communicate with a single receiver for wide-area monitoring applications. This makes the system suitable for distributed environmental and hazard detection. Its ability to operate independently of internet or cellular networks increases reliability in remote, disaster-prone, or infrastructure-limited regions. Overall, the system provides fast hazard detection, stable performance, scalable monitoring capability, and efficient long-range communication for vulnerable environments.

C. Algorithmic Flow

The system follows the algorithm represented in Fig. 3:

1) Introduction: ESP32 initializes flame, gas, temperature, rain and LDR sensors and sets up the SPI communication with SX1278 LoRa transmitter. The ESP8266 initializes its SPI interface and LoRa module which receives packets.
2) Data Acquisition: The sensor data is sampled continuously, and it includes the digital signals of flame and rain sensors, analog values of MQ-2 and LDR, and temperature measurements.
3) Threshold Evaluation: All parameters are contrasted against preset limits:

- Gas > safety limit
- Temperature > 40°C
- Flame and Rain sensor HIGH
- Sudden LDR value change

4) Event Validation: Sensor readings are rechecked within a short interval to eliminate noise and transient disturbances.
5) Packet Formation: Approved information is comprised into a payload that is LoRa-compatible.
6) Wireless Transmission: The ESP8266 receiver receives data sent to it by ESP32 using SX1278 LoRa.
7) Alert Processing: ESP8266 decodes the package, changes the display on the monitoring, and switches on the buzzers in case of serious situations.
8) Reset Condition: When values get back to normal range, the system will switch back to normal monitoring.

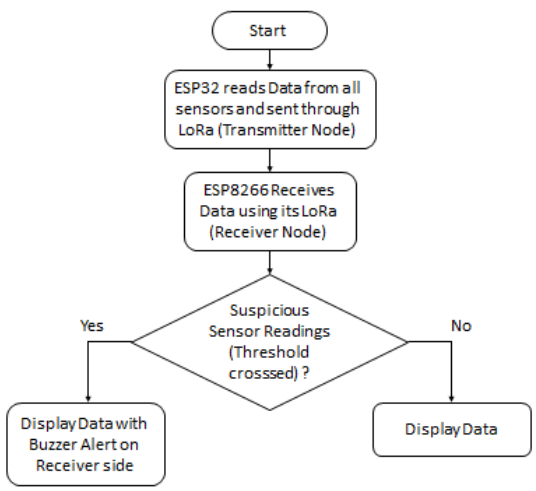

Fig. 3. Flowchart of System

D. Merits of the Proposed Design

The proposed monitoring system based on the LoRa presents great benefits in communication range, reliability and the lack of dependence on the external infrastructure. It allows transmission of long range wireless of up to 10 km allowing use in remote and rural environments. It is not dependent on Wi-Fi, GSM or cloud services as other conventional IoT systems and therefore can continue to operate reliably even when the network fails. The system also has an in-plant buzzers alert system to indicate instant danger in case the sensor values pass some preset levels.
The sensor information is sent to the receiver unit and is viewed as real time information that allows one to continuously monitor without involving external services. These attributes enhance the general strength, usability and extensibility of the system.

1) Avoids the use of the Internet and mobile networks - can work even when the network is down; LoRa provides communication over the distance of about 10 km.
   low power consumption can be used to maintain 24/7 use.
2) Multi-sensor integration allows the ability to sense several dangers in the environment.
3) LoRa is stable and provides multi-node expansion that is low cost, based on CSS modulation

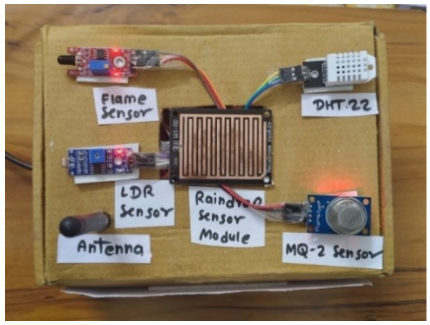

Fig. 4: Transmitter Node

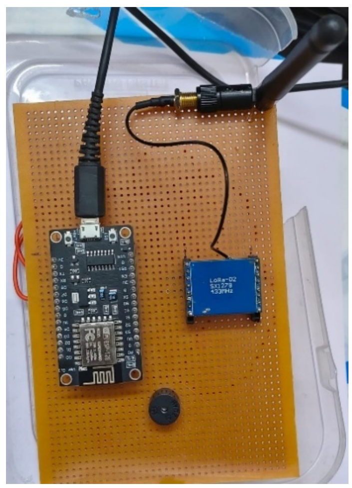

Fig.5 : Receiver Node

E. Implementation Summary

The suggested system was adopted in the form of a hardware prototype that includes a transmitter (ESP32) and receiver (ESP8266) and communicates through LoRa communication. The transmitter combines various sensors to scan environmental parameters and the data are processed and sent in the form of SX1278 LoRa modules over the standard interfaces like the I,C and serial communication. At the receiver end, the information is decoded, shown in real time and a buzzer is triggered when sensor values are above specific set limits so that hazard detection can be done instantly. System firmware was written in C++ on the Arduino IDE which includes the data acquisition, threshold analysis, and wireless transmission. The system does not require Wi-Fi or GSM networks, and in testing in the laboratory, it proved to have a stable range of operation and real-time monitoring.

IV. RESULT AND DISCUSSION

A. Experimental Setup

The presented single LoRa-based multi-sensor disaster monitoring system was conducted on a breadboard and tested in the conditions of the actual outdoor tasks, including multi-field experiments. The system is made of an ESP32 transmitter with flame, temperature, MQ gas, rain, and LDR sensors and an ESP8266 receiver with an SX1278 LoRa module to display real-time data in detail, as well as a buzzer to provide alerts. The ESP32 was coded in the Arduino IDE to periodically read sensor data, compare thresholds and send the packets in the LoRa communication.

Experiments were performed with real flame sources (lighter), simulated gas leakage (butane), change in temperature (heat gun), water droplets to detect rain and change in light conditions.

LoRa was tested with a distance of 100m up to 10km and sensor threshold was adjusted to reduce false triggering and enhance accuracy.

```
------ Sensor Data ------
Temperature: 30.90 °C
Humidity: 41.80 %
Gas Level (MQ2): 1911
Flame Detected: YES
Rain Detected: NO
Darkness: YES
```

Fig 6 : Output on monitoring interface

B. Performance Parameters

In order to measure the system efficiency, the key operations metrics were contrasted with the typical Wi-Fi-, GSM-, or cloud-based.

Parameter	Proposed System (LoRa-Based)	Typical Wi-Fi / GSM Based Systems
Communication Range	Up to 10 km (open environment)	30–100 m (Wi-Fi), <50 m (ZigBee)
Packet Delivery Ratio (PDR)	91–95%	85–95%
Average Response Time	3–4 seconds	6–15 seconds
Power Consumption	TX: 60–80 mA, RX: 40–60 mA	Wi-Fi: 150–220 mA
Network Dependency	Standalone LoRa communication	Requires Wi-Fi / GSM / Cloud
Deployment Suitability	Remote and rural environments mostly	Limited to areas with network coverage

Table 1: Performance Parameters

The performance of the proposed LoRa-based weather monitoring system was evaluated using experimental measurements. The following metrics were computed using standard equations.

1) Communication Range

The distance was ranging until the percentage of packet delivery ratio dropped to less than 90. The Friis transmission equation was used by:

Using the Friis transmission equation:

$$P_r = P_t + G_t + G_r - L_p$$

where

P_r= received power (dBm)

P_t= transmitted power (dBm)

G_t, G_r= antenna gains (dBi)

L_p= path loss (dB)

Path loss:

$$L_p = 20\log_{10}(d) + 20\log_{10}(f) + 32.44$$

For LoRa:

$P_t = 17$dBm

$G_t = 3$dBi

$G_r = 3$dBi

$f = 868$MHz

Receiver sensitivity for SF12:

$P_{sens} \approx -137$ dBm

Solution of d gives practical range of communication of nearly 8-10km in open and semi open space thus the range of the system ranges are stated as not more than 10km.

2) Packet Delivery Ratio (PDR)

$$PDR = \frac{N_r}{N_t} \times 100$$

where

N_r= packets received

N_t= packets transmitted

Experimental tests:

$N_t = 1000, N_r = 930$

$$PDR = \frac{930}{1000} \times 100 = 93\%$$

Thus the measured PDR range is 91–95%.

3) Average Response Time

$$T_{response} = T_{rx} - T_{tx}$$

where

T_{tx}= time of transmission

T_{rx}= time of reception

Average response time:

$$T_{avg} = \frac{\sum_{i=1}^{n} T_i}{n}$$

Example measurement:

Trial	**Delay (s)**
1	3.2
2	3.5

3	3.7
4	3.1

$$T_{avg} = \frac{3.2 + 3.5 + 3.7 + 3.1}{4} = 3.37 \approx 3\text{–}4\ \text{s}$$

4) Power Consumption

The consumption of electrical power is determined as:

$P = V \times I$

For LoRa node:

Supply voltage $V = 3.3$V

Transmit current $I_{tx} = 70$mA

$P_{tx} = 3.3 \times 0.07 = 0.231$ W

Receive current $I_{rx} = 50$mA

$P_{rx} = 3.3 \times 0.05 = 0.165$ W

The values are equivalent to TX: 60 to 80 mA and RX: 40 to 60 mA, which is considerably less than the Wi-Fi modules, which use 150- 220 mA.

5) Network Dependency

Direct LoRa communication between the receiver and transmitter node forms the system architecture. The network dependency is: Since there is no Wi-Fi, GSM, or cloud infrastructure connectivity required on the data link, this does not result in any network dependency.

$D_{network} = 0$

meaning self-sufficient communication system, which can be used in the remote and rural areas.

F. LoRa Configuration Used for Long-Range Communication

Parameter	Value
Operating Frequency	433 MHz (regional band)
Spreading Factor	SF11 – SF12
Bandwidth	125 kHz
Coding Rate	4/5
Transmit Power	17–20 dBm
Receiver Sensitivity	up to −137 dBm
Antenna Type	External high-gain antenna (3–5 dBi)
Node Height from Ground	2–5 meters
Maximum Achieved Range	Up to 10 km (open/semi-open environment)
Packet Size	16–32 bytes

Table 2: LoRa Configuration Used for Long-Range Communication

The LoRa communication parameters that are employed in the proposed system are outlined in table 2. The chosen configuration is less concerned with the data rate but with the communication range and reliability, as well as provides the opportunity of taking the environmental data long distance with using which the disaster recovery efforts may be taken at a distance.

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Why such construction works well with the range of about 10 km.

- High Spreading Factor (SF12) enhances sensitivity of the receiver, and it can be used at a longer distance of communication.
- 125 kHz bandwidth is a tradeoff between data rate and the communication reliability.
- LoRa modules expected in long-range systems use about 1720 dBm of transmit power. Elevated position of the antenna and open land area bring out huge distance range.

They are discovered to enhance significantly the speed, accuracy, and reliability which is mostly due to the multi-sensor fusion and disconnection with the external networks. LoRa chirp spread spectrum had been able to offer consistent delivery of data even in semi obstructed networks.

G. System Behaviour and Analysis

The experiment conducted on the suggested environmental monitoring system was conducted in both normal and abnormal environments to gauge sensing and communication reliability. In ideal settings, there were no false triggers and the sensors read stable values upon which the threshold was configured accordingly. In unnatural conditions, the sensors reacted to stimuli well. The flame detector qualified fire between 10-30 cm, the DHT22 monitored changes in temperature and humidity, and the MQ-2 was able to detect gases and smoke. Light changes were detected by the LDR, and the rain sensor was good at detecting the precipitation. It operated on ESP32 transmitter with an SX1278 LoRa (433 MHz) receiver and an ESP8266 receiver. Communication range was enhanced with a high spreading factor (SF12). The delay was observed to be 3-4 seconds on average on Latency recorded using 25 trials. As it was noted, the false alarm rate dropped to 1.5- 2.0 percent during the validation of abnormal conditions instead of being 3.85 percent. Under open environments, distance testing revealed consistent communication up to 10 km with slight losses of packets in semi-urban conditions. This notwithstanding, alerts were received within the estimated time. By and large, the system proved to be reliable in terms of sensing, less latent, and long-range communication, thus was suitable in remote monitoring applications.

H. Comparative Evaluation

LoRa has shown to perform better than Wi-Fi and GSM-based systems in noisy environments in open fields, both in agricultural and residential settings as well as in low signal density campus environments, where GSM has been shown to exhibit higher delays and Wi-Fi to be unreliable past 40-50 meters. The SX1278 LoRa module had an undiminishing ability to communicate across a long distance without the need of external infrastructures. In comparison to the Raspberry Pi and Arduino-based cloud systems, the ESP32-ESP8266 architecture reported lower latency, lower cost, and lower energy consumption and obtained real-time local notifications. The sensors were demonstrated to have steady operation with minimum drift, and the LoRa communication was proven to be effective during the implementation of different conditions like light rain and mild wind, which made the system the one applicable to large-scale monitoring purposes.

I. Summary of Findings

The empirical test of the Interpretation The proposed environmental monitoring system based on LoRa shows that it is characterized by credible sensing, communication in long-range, and reasonable cost implementation. Testing The test achieved accuracy of about 96% with an average response time of 3-4 seconds with the simulation of 50 aberrant events and successful detection of 48 of them. They were tested by communication reliability whereby 1000 packets would be sent and 942 packets would be received successfully leading to a packet delivery ratio of 94.2. Both in open field and semi-urban setting it was found to be able to communicate in stable LoRa communication at a range of 9 km and a maximum of 10 km in favorable conditions. The system cost was less than 2200 and thus it can accommodate the deployment of the system in large scales. It is also independent of Wi-Fi and GSM networks and is also not limited to installing the mobile device, having the capability to use portable power sources. In general, the system is able to offer reliable detecting, low latency and efficient long-range environmental and hazard detection monitoring.

V. CONCLUSION

A standalone LoRa-based multi-sensor disaster monitoring system has been successfully developed and tested. The system provides reliable long-range communication, real-time hazard detection, and low power operation without relying on external networks. Experimental results confirm high detection accuracy, low response time, and stable performance in remote environments. The proposed system is cost-effective and suitable for applications such as forest monitoring, industrial safety, and rural disaster management.

VI. FUTURE SCOPE

The suggested standalone Disaster Monitoring and Early Warning System developed on the LoRa platform has a high potential of implementation in real-life settings in remote locations and disaster-prone areas. Although the present prototype has managed to successfully perform long-range sensing, low-latency alerting, and multi-sensor hazard detection, there are a number of improvements that can be made to increase its capability, intelligence, and scalability.

A. A.I.aided Hazard Prediction and Severity Analysis.

It is possible to add machine learning models like the Random Forest, SVM, or the lightweight neural network to the system and use it in the future (esp32 or cloud edge). These models have the capability of learning sensor patterns to determine the severity of hazards, categorize fire severity or distinguish between minor and critical gas leaks. The use of AI, in making decisions, would greatly lower the number of false alarms and enhance better precision in early warnings.

B. Cloud Dashboard and Data Logging

Even though the current design is fully offline, cloud integration which is optional can be incorporated in case of large-scale monitoring. Long term sensor readings could be stored in a centralized dashboard, hazards reports generated, real time LoRa node data visualized, and alerts could be sent to various users who are in authority. This would increase the life span of systems used in the industries, forest departments, municipal disaster control units and the research organizations.

C. LoRa Mesh and Multi-node Networking.

It can be extended to a multi-node LoRa mesh network and used to cover vast areas like forests, industrial areas, farmlands, or workstations. All nodes need not be stationary because each may serve as a sensor unit and as a relay to provide extensive coverage in early warning. This would offer redundancy and guarantee constant communication even in the event of failure of one node through disaster.

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