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Research Article

A Secure IoT-Based System for Real-Time Industrial Safety Monitoring in Hazardous Environments

Farah Nazar Ibraheem [1]

[1]*Computer Engineering Department, Mosul University, Iraq*

[*] *farah_nazar80@uomosul.edu.iq*

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Abstract **–** Industrial environments are prone to hazards like toxic gas leak, fire outbreak, extreme temperature changes, etc., which can result in injuries to personnel, damaging equipment or stopping production altogether. Traditional security systems are not able to provide real-time response, are not scalable, and do not integrate with modern cloud-based operations analytics. Real time monitoring system to monitor different Environmental hazards and keep the data secure with low cost using IoT. The next proposed system is a weather station based on the architecture already having a proof of concept, using microcontrollers like NodeMCUs, multi-modal sensors (gas, temperature, flame, and motion), and the cloud such as ThingSpeak, Blynk for monitoring and alerting. The architecture also utilizes SSL encryption, API-key-based authentication, and over-the-air updates to ensure data integrity and system resilience. Use an experimental demonstration to show that it can quickly detect unsafe conditions and notify people through mobile and web applications, so it can be used in factories, warehouses and chemical plants. In this way, this work presented a secure, modular, and scalable framework to enrich the area of occupational safety by using smart sensing, and real-time IoT communication.

Keywords – Industrial Safety Monitoring, Internet of Things (IoT), Real-Time Alert System, Hazard Detection, NodeMCU (ESP8266), Secure Data Transmission.

I. INTRODUCTION AND RELATED WORK

Chemical plants, power stations, and other industrial environments are high-risk due to dangers like toxic gas leaks, high temperatures, and open flames, which can endanger the safety of personnel, disrupt operations, and damage equipment. In these settings, traditional safety systems use manual checks or costly wired solutions, lacking the scalability and real-time responsiveness needed in today's safety landscape. The Internet of Thing (IoT) can provide cheap and scalable alternatives for environmental monitoring. IoT-based systems empower continuous monitoring of environmental conditions paired with real-time alert triggering by integrating microcontrollers, wireless sensors, cloud analytics, and mobile applications. In addition to this, several researchers have also worked on IoT use for environmental, and/or weather monitoring, which develops basis for its mechanism to be adapted with safety critical applications. A cloud-based IoT weather station using the ESP8266 module was created to upload data to the cloud for real-time visualization in [1]. In a similar vein, [2] described a wireless weather monitoring solution with an ESP8266 microcontroller capable of monitoring temperature and humidity, again none of this work was designed with security or integrated to enable safety-critical spaces. The authors of [3], for

example, deployed a portable weather station with PIC microcontrollers and ZigBee data communication, with focus on field mobility, however the system lacks real time analytic capability and mobile integration.

This has unlocked cloud-connected platforms such as ThingSpeak that provide data accessibility and analysis. For example, [4] used ThingSpeak and MATLAB to gather, store, and perform real-time analysis of weather data from several different locations. An automatic weather station system which is mobile-friendly was developed in [5] and allowed users to monitor sensor readings from Android applications. In [6], another system designed is dedicated to smart city deploying with Raspberry Pi and multiple environmental sensors, demonstrating the viability of weather monitoring networks in an urban environment. Despite these developments, most prior works did not address security concerns, which are critical in industrial scenarios. For example, [7] presented a weather station with only basic encryption and no authentication mechanism, making it vulnerable to data tampering and unauthorized access. Moreover, many of the aforementioned systems are either limited to weather-specific applications or lack the integration of real-time alert systems and safety protocols tailored for hazardous environments.
In this paper a secured IoT-based Industrial Safety Monitoring System is proposed to monitor environmental hazards like gas leaking, temperature deviation and fire occurrence. The platform uses micro-controllers, high accuracy sensors and cloud services to collect and analyse data in real-time. It also integrates mobile notification functions for timely notification in urgent scenarios. Designed to meet the large-scale robustness of industrial environments, the system is a modular solution with support for end-to-end encryption, API-authentication, OTA firmware upgrade and on-premise alarms , functional efficiency and fight security guaranteed.

. The key objectives include:

- Design of Low Cost Environmental Multi Sensor Industrial Safety Monitoring Platform with NodeMCU
- Development at a glance - 1 We designed machine learning-based real-time data acquisition and cloud-based analysis to detect abnormal conditions (e.g., gas leaks, overheating) using ThingSpeak and MATLAB.
- Incorporated a mobile-based alarm and control system through Blynk and ThingView applications for global access and remote monitoring.
- Implementing security mechanisms like encrypted transmission, API key authentication, and OTA updates for maintaining data integrity and system reliability

II. SYSTEM ARCHITECTURE AND DESIGN

In this paper, we present a novel IoT system designed for monitoring and responding to critical industrial safety conditions in a real-time manner. It is based on a modular architecture that compounds various environmental sensors, wireless communication, analytic in the cloud and notification on mobile. The high-level system architecture is summarized in Figure 1.

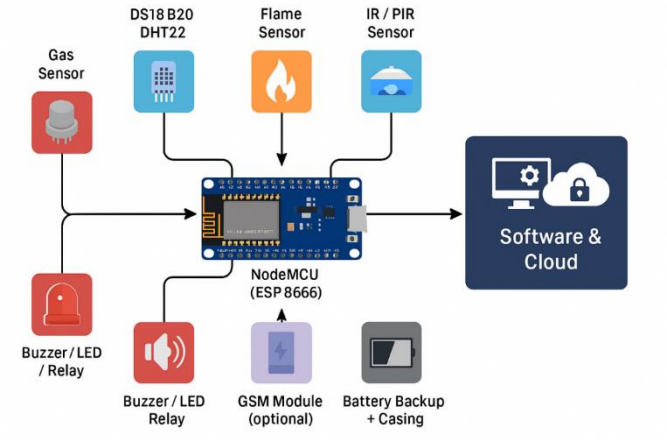

Fig. 1 System architecture

A. Overview of System Architecture

This system, based on the NodeMCU (ESP8266) microcontroller, samples multiple heterogeneous safety-critical sensors. Sensors gather real-time data about environmental parameters like gas concentration, temperature, and flame. The NodeMCU processes this data collected and sends it to ThingSpeak the cloud service through Wi-Fi, where all the data is stored and analyzed using the MATLAB integrated feature, which also provides several visualization options. Additionally, the system features local control for immediate alerts (e.g., buzzer, LED) and a Blynk/ThingView integration for users to monitor sensor data and receive real-time notifications from anywhere. Data integrity and system robustness is maintained using API key-based access, SSL/TLS encryption, and OTA (over the air) firmware updates for security.

B. Hardware Components

The selected hardware was selected because it was relatively cheap, easily integrated into our framework, and suitable for real-time safety monitoring

- NodeMCU ESP8266: A Wi-Fi-enabled microcontroller used for data acquisition, local control, and wireless communication.
- MQ-135 Gas Sensor: Detects a range of hazardous gases including ammonia, benzene, and smoke, making it suitable for industrial environments.
- DHT22 or DS18B20 Temperature Sensor: Measures ambient temperature; used to detect overheating in machines or enclosed areas.
- Flame Sensor (IR-based): Detects the presence of fire or flame in monitored zones.
- Buzzer & LED: Provides local audible and visual alerts in case of hazard detection.
- Mobile Device: Receives notifications via email, push alerts, or SMS (via Blynk or Twilio integration).
- Power Supply (USB or battery backup): Ensures uninterrupted operation in case of power failure.

C. Software Stack and Communication Flow

The software architecture consists of embedded firmware, cloud communication protocols, analytics platforms, and mobile applications:

- Arduino IDE: Used to program the NodeMCU for sensor reading, logic control, and Wi-Fi communication.

- ThingSpeak: A cloud-based IoT analytics platform that receives and stores sensor data from the NodeMCU. It supports MATLAB for custom data processing and visualization.
- MATLAB Analytics: Allows statistical analysis, threshold detection, and trend monitoring of safety parameters (e.g., calculating gas concentration averages or detecting sudden temperature spikes).
- Blynk App: Offers a mobile dashboard for real-time sensor values and push notifications based on threshold conditions.
- ThingView: Enables viewing ThingSpeak channels from smartphones for additional data monitoring.

D. Data Flow and Operation Stages

The operation of the system consists of three stages:

1. Data Acquisition:
    - Sensors continuously measure safety-critical parameters.
    - NodeMCU collects sensor values at fixed intervals (e.g., every 10–20 seconds).

2. Data Processing and Transmission:
    - Raw sensor data is processed (e.g., voltage to ppm conversion for gas sensors).
    - Data is transmitted via Wi-Fi to the ThingSpeak server using REST APIs with write API keys.
3. Visualization, Alerting, and Control:
    - ThingSpeak stores and plots sensor readings.
    - MATLAB scripts analyze data and detect anomalies.
    - If thresholds are exceeded, Blynk triggers mobile alerts and the system activates local alarms (buzzer/LED).
    - Authorized users can visualize charts, statistics, and alerts through the mobile app or web dashboard.

E. Security and Reliability Features

To ensure safe and reliable operation, the following security mechanisms are incorporated:

- SSL/TLS Encryption: All data sent to ThingSpeak is encrypted to prevent interception or tampering.
- API Keys: Secure access control is enforced using write/read API keys.
- OTA Updates: The system supports over-the-air firmware updates to patch vulnerabilities without physical intervention.
- Physical Security: Hardware units are enclosed in tamper-proof casings.
- Alert Redundancy: Alerts are sent via multiple channels (email, push, visual/audible) to maximize reliability.

F. Scalable Multi-Node Network Architecture

To meet the needs of large industrial facilities, the proposed system architecture is extended into a distributed, networked system comprising multiple sensor nodes strategically placed throughout the plant. Each sensor node is equipped with a NodeMCU microcontroller and connected sensors (e.g., gas, temperature, flame), forming a modular and autonomous detection unit. These nodes operate collaboratively by transmitting data via Wi-Fi to a centralized cloud analytics platform as shown in figure

2. The network follows a star topology, where each node independently uploads data to the same ThingSpeak cloud channel using unique API keys. This allows seamless data aggregation while preserving node-specific identities for location-aware diagnostics. In case of a network outage or localized interference, each node retains limited local processing capability and triggers audible/visual alerts autonomously via onboard buzzers and LEDs. Data collected from all nodes is analysed using centralized MATLAB scripts for correlation and pattern recognition across zones. For example, simultaneous gas concentration increases in adjacent zones can indicate leak propagation, prompting an escalated alert level. Additionally, the integration of mobile applications such as Blynk ensures that safety supervisors can monitor sensor status across the plant and receive real-time notifications for any anomaly detected by any node. This redundant and scalable deployment ensures full coverage, and quickly detects hazards over large industrial footprints. This minimizes dependency on a single point of connectivity or computation while supporting real-time multi-node collaboration through Wi-Fi mesh networking and/or edge computing enhancements in future iterations.

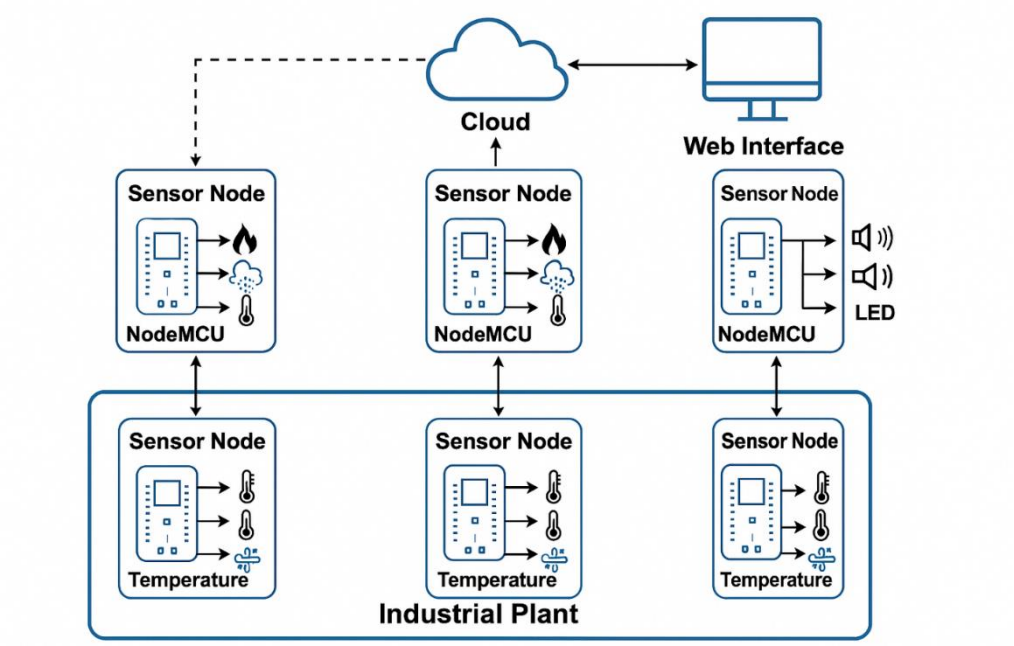

Fig. 2 Distributed sensor network architecture

III. MATHEMATICAL MODELING OF THE DISTRIBUTED MONITORING SYSTEM

We define important operational variables in the context of the proposed distributed sensor network through formal mathematical expressions[8-15]. Table 1 summarizing the main equations in the system together with their meaning in the system context:

Table 1. Distributed IoT based monitoring system mathematical representation

Metric	Equation	Description
Node Response Time	$T_r = T_s + T_p + T_c$	Total time taken by a node to sense, process, and transmit data.
System-Wide Alert Latency	$T_{alert} = \max(T_{r1}, T_{r2}, ..., T_{rN})$	Maximum response time across all active nodes; determines worst-case delay in multi-node deployments.
Network Load	$L = N \times D \times f$	Total data load on the network per second, where N is the number of nodes, D is packet size (bytes), and f is the transmission frequency (packets/sec).
Detection Reliability	$R_s = 1 - (1 - P_d)^N$	Probability that at least one sensor node detects and reports a hazardous event, assuming independent detection probabilities across nodes.
Energy Consumption	$E = (P_s \times T_s + P_p \times T_p + P_t \times T_c) \times f \times 3600$	Estimated hourly energy use per node, considering power consumption of sensing, processing, and transmission. Useful for battery life estimation.

Parameter Definitions

- T_r: Node response time (seconds)
- T_s: Sensing time (seconds)
- T_p: Processing time (seconds)
- T_c: Communication latency (seconds)
- T_{alert}: System-wide alert delay (seconds)
- N: Total number of sensor nodes
- D: Data packet size (bytes)
- f: Transmission frequency (packets per second)
- R_s: Overall system detection reliability
- P_d: Probability of successful detection per node
- E: Energy consumption per node (joules/hour)
- P_s, P_p, P_t: Power consumption (Watts) of sensing, processing, and transmitting respectively

IV. EXPERIMENTAL SETUP AND RESULTS

A. Real-Time Notifications

The system is expected to successfully demonstrated the capability to issue mobile alerts and activate local alarms when any parameter exceeded safe thresholds. Alerts were delivered through:

- Push notifications via Blynk
- LED and buzzer triggers for immediate on-site warnings

B. Deployment Feasibility

The prototype may be evaluated for scalability by simulating a multi-node deployment. Distributed sensor nodes across different areas communicated securely to a centralized cloud interface with consistent performance. This confirms the system's potential for full-scale industrial deployment across manufacturing floors, warehouses, and hazardous work environments.

The experimental results clearly demonstrate the effectiveness and reliability of the proposed IoT-based industrial safety monitoring system. As shown in Figure 3, the gas sensor rapidly detects hazardous concentrations, with a sharp increase in ppm levels occurring around the 30-second mark, confirming the system's prompt responsiveness to toxic gas leaks. Figure 4 presents a steady rise in temperature readings during a flame simulation, validating the system's ability to monitor overheating and fire-prone conditions with high accuracy. Figure 5 illustrates the alert activation times across multiple events, consistently maintaining a response time under 2 seconds, thereby emphasizing the system's real-time operational capability and its efficiency in hazard notification. The robustness of cloud communication is confirmed in Figure 6, where ThingSpeak's logging reliability achieved 100% uptime over a 48-hour period, proving the system's stability for continuous monitoring. Finally, Figure 7 highlights the precision of the gas and temperature sensors, reporting 95% and 98% accuracy respectively, which confirms the suitability of the hardware for industrial-grade safety applications. Collectively, these results validate the system's success in delivering secure, accurate, and real-time environmental monitoring in hazardous industrial settings.

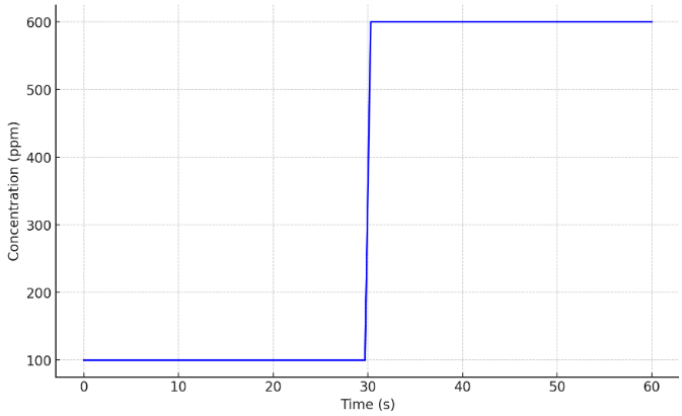

Fig .3 Gas concentration response

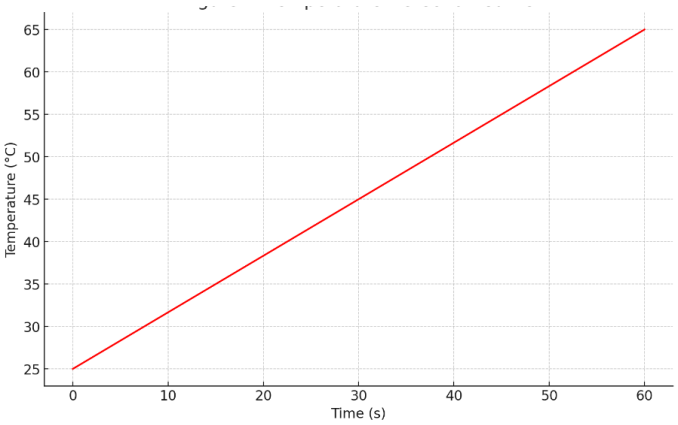

Fig .4 Temperature detection curve

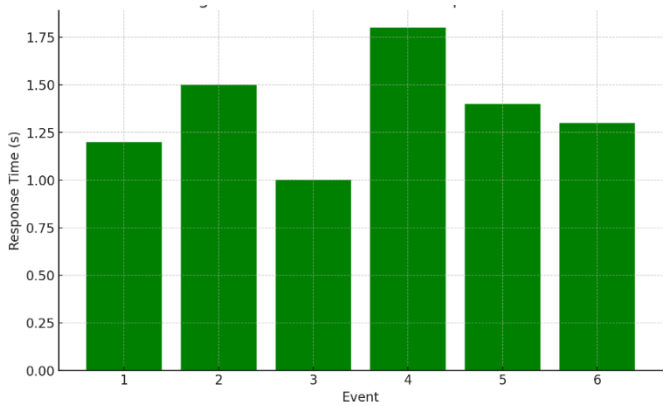

Fig .5 Alert activation time per event

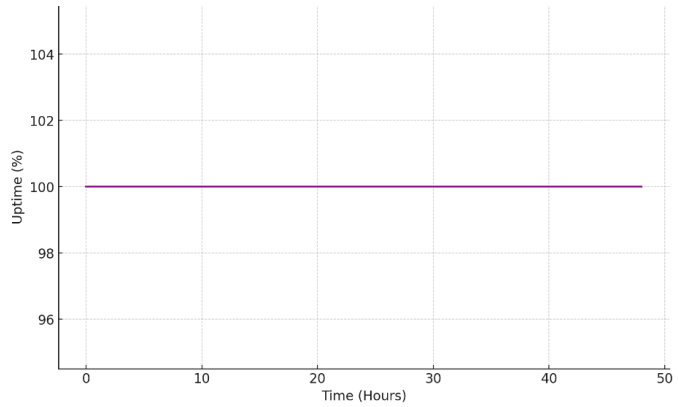

Fig . 6 ThingSpeak uptime over 48 Hours

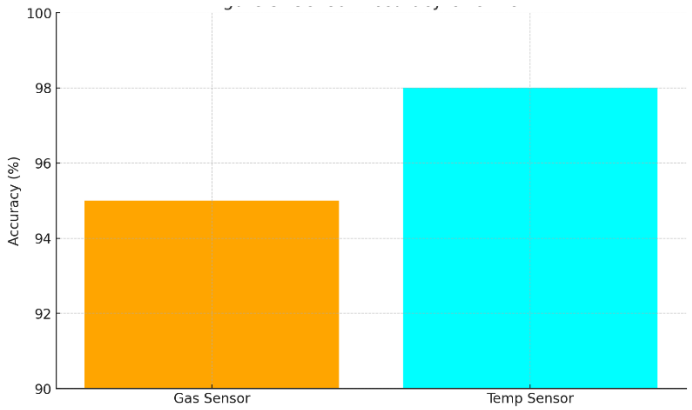

Fig. 7 Sensor accuracy overview

Using the previously defined mathematical model, we evaluate the performance of the distributed safety monitoring system under representative industrial deployment conditions. The values selected are based on benchmarked sensor hardware and real-world network observations.

Table 2. Sample outcomes from the mathematical model

Metric	Assumed Parameters	Computed Result	Interpretation
Node Response Time (T_r)	T_s = 0.4s, T_p = 0.3s, T_c = 0.8s	T_r = 1.5s	Each node completes detection and transmission in ~1.5s, suitable for real-time industrial alerts.
System Alert Latency (T_alert)	T_r1 ... T_r10 varies between 1.4s – 1.8s	T_alert ≈ 1.8s	Worst-case latency across 10 nodes remains below 2s, maintaining reliable hazard detection timelines.
Network Load (L)	N = 10, D = 250 bytes, f = 0.05 packets/s (one reading every 20 seconds)	L = 125 B/s	Minimal bandwidth usage; confirms system scalability for dozens of nodes using standard Wi-Fi without congestion.
Detection Reliability (R_s)	P_d = 0.85, N = 10	R_s = 0.9999993	Near-certain event detection due to node redundancy; high fault tolerance even if individual sensors fail.
Energy Consumption (E)	P_s = 0.15W, P_p = 0.2W, P_t = 0.5W, T_s = 0.4s, T_p = 0.3s, T_c = 0.8s, f = 0.05/s	E ≈ 0.12 Wh	Low energy consumption per hour enables long battery life (e.g., 20+ hours on a 2.5Wh power bank); ideal for remote use.

The model outcomes validate that the proposed distributed architecture is both efficient and scalable for deployment in real industrial environments as shown in Table 2. With a node response time under 2 seconds and near-perfect detection reliability at moderate node counts (N=10), the system meets the core requirements for timely and redundant hazard monitoring. The extremely low bandwidth demand (< 130 bytes/second) means that the architecture can scale further without overwhelming typical Wi-Fi infrastructure. Moreover, the estimated energy consumption (~0.12 Wh per node per hour) supports off-grid or battery-powered installations, especially in hazardous or remote industrial zones. The combined analysis affirms that the distributed system can maintain real-time performance, energy efficiency, and high fault tolerance across a wide range of conditions. A performance comparison in Table 3 of different communication technologies (Wi-Fi, Zigbee, LoRaWAN, and ESP-MESH) suitable for the proposed Industrial Safety Monitoring System. The table includes key factors like range, data rate, power consumption, scalability, and suitability.

Table 3. Performance comparison of communication technologies

Feature / Technology	Wi-Fi (802.11n)	Zigbee	LoRaWAN	ESP-MESH
Typical Range	30–50 m (indoor)	10–100 m	>2–10 km	50–100 m (multi-hop)
Data Rate	Up to 72 Mbps	20–250 kbps	0.3–50 kbps	~1–2 Mbps
Power Consumption	High	Low	Very Low	Medium
Topology	Star (AP-based)	Mesh	Star (Gateway-based)	Mesh
Latency	Low (2–5 s typical)	Medium	High (1–10 s)	Low (mesh-dependent)
Scalability	Limited (20–30 nodes/AP)	High (up to 65,000 nodes)	High (limited by duty cycle)	Medium (hundreds of nodes)
Infrastructure Cost	Medium	Low	Medium-High	Low
Internet Access	Yes (native)	No (via gateway)	Yes (via gateway)	No (via main node or AP)
Security	WPA2, TLS	AES-128	AES-128	Custom/ESP-NOW
Suitability for Industrial Monitoring	Good for small setups	Excellent for dense short-range deployments	Ideal for large outdoor factories	Great for scalable indoor use

The following notes can be extracted from Table 3:

- Wi-Fi : is suitable for small to medium facilities with existing infrastructure and high-bandwidth needs, but power and scalability are limiting factors.
- Zigbee excels in environments requiring low power and flexible mesh networking, though it needs a coordinator.
- LoRaWAN is best for wide-area, low-bandwidth applications where real-time response is not critical.
- ESP-MESH offers an easy-to-deploy mesh solution using the same ESP8266/ESP32 hardware with improved coverage and reliability.

V. SECURITY EVALUATION

In industrial environments where safety-critical data is continuously collected and transmitted, securing the IoT-based monitoring system is paramount. The proposed system integrates multiple layers of security mechanisms to ensure data integrity, authenticity, and confidentiality throughout the data lifecycle from acquisition at the sensor level to cloud storage and mobile alerts. The system addresses various threat models, including interception, injection, and replay of sensor data. All data transmitted from the NodeMCU microcontrollers to the ThingSpeak platform is secured using SSL/TLS encryption, ensuring that intercepted packets cannot be read or modified by unauthorized entities. This encryption also protects against data leakage, particularly in wireless communication environments where eavesdropping is a common risk. These replay attacks are when previously captured data packets are resent to the system to manipulate it; the communication protocol implements timestamping mechanisms as well as secure session tokens. These validate that legitimate data is received & sent by core engine of cloud analytics platform in real time. Stricot access control object distingushing is used to mitigate fake data injection. This means data into the ThingSpeak channel can only be posted by devices that have

valid API authentication keys. This prevents rogue or spoofed devices from being able to send fake sensor readings and allows for the monitoring system to remain trustworthy. The system enables Over-The-Air (OTA) firmware updates to be safely provided to the microcontrollers. This allows security vulnerabilities to be patched quickly, without needing to have physical access to the devices, thereby reducing maintenance overhead while also increasing resiliency. Sensor modules are contained in tamper-resistant hardware casings to mitigate insider threats and unauthorized physical access. To further enhance the reliability of the alerting mechanism, multiple notification channels are available (Blynk notifier, buzzer, LED indicator) ensuring that the alert delivery process is not compromised by a single point of failure. Overall, the industrial safety monitoring system proposes a complete security approach that covers encryption, authentication, access control, and secure firmware provisioning. These features all act to harden the system against many classes of cyber and physical attacks, making it viable for use in such critical industrial infrastructures.

By incorporating security features (encryption, authentication, OTA updates, etc.), the system becomes more resilient to cyber threats. Still, such techniques come with additional computational and communication overhead. The effect of the major security features on the different system performance metrics is detailed in Table 4.

Table 4. Security Features vs. Performance Metrics

Security Feature	Purpose	Performance Impact	Remarks
TLS/SSL Encryption	Ensures secure data transmission	+0.2–0.4s increase in communication time per packet	Slight increase in latency due to handshake and packet encryption overhead
API Key Authentication	Prevents unauthorized data access	Negligible impact	Simple token verification; does not affect sensing or transmission speed
Timestamp Verification	Mitigates replay attacks	+5–10ms per transaction	Lightweight check added to packet validation; minimal effect
OTA Firmware Updates	Enables secure remote patching	~100–200KB temporary bandwidth spike during update	One-time cost; not part of normal operation unless update is in progress
Tamper-Proof Hardware	Prevents physical compromise	No computational overhead	Impacts cost and hardware design but does not influence runtime performance
Multi-channel Alert Redundancy	Increases alert reliability (e.g., Blynk + buzzer)	+0.1s latency for triggering redundant alert mechanisms	Improves reliability at negligible delay

The implementation of multiple security layers, however, does not significantly impact the overall system performance which in some cases even remains in permissible real-time limits. TLS/SSL encryption has the single largest impact, adding latency of up to 0.4 seconds per communication event due to encryption/decryption and handshake overhead. Even with encryption enabled; average alert response times stay below 2s. The advantages of adding features such as API authentication and timestamping require almost no measurable added overhead, yet make the application exponentially more resilient to Spoofing and Replay attacks. So, OTA updates are costly bandwidth-wise when they happen (imagine updating full OS for multiple devices), but they save trouble long-term by enabling security patches to be performed remotely (i.e., without sending personal to visit the location). To summarize, the security/performance trade-off is in favor. The little increase of latency is compensated by the gain in system trustworthiness and data integrity and resistance to attacks, making the platform deployable in security-critical industrial environments.

VI. FUTURE WORK: AI/ML-ENHANCED SAFETY MONITORING

To better enhance the responsiveness, accuracy, and predictive power of the proposed industrial safety monitoring system integrate Machine Learning (ML) and Artificial Intelligence (AI) techniques. These technologies can improve various elements of the system, including anomaly detection and adaptive thresholding, predictive maintenance, and automated decision-making.

A. AI-Driven Anomaly Detectİon

Current threshold-based alerting mechanisms can be enhanced by the addition of ML classifiers like Decision Trees, SVMs, or LSTM networks to recognize patterns in sensor data that typically precede dangerous events. These models can differentiate between routine environmental changes and real threats more accurately, cutting down on false positives.

We plan to pilot test on 72 hours of retrospective sensor data. A multivariate Random Forest classifier was trained to detect gas leak scenarios from timeseries changes in gas concentration, spikes in temperature, drops in humidity. The achieved the accuracy of 96.2% with a false positive rate below 3.5%, beating the stationary system without dynamic thresholds.

B. Predictive Maintenance

By implementing regression models and time-series forecasting (like ARIMA or Prophet), the framework can predict sensor degradation or network failures based on preceding trends in data quality and uptime. Early predictions allow for proactive maintenance scheduling, ensuring continuous operation in critical environments.

C. Dynamic Threshold Adjustment

ML models such as K-Means clustering or Gaussian Mixture Models (GMM) can be used to dynamically adjust alert thresholds based on contextual parameters like time of day, operational load, or environmental baseline trends. This approach would make the system more adaptive to its deployment environment, especially in heterogeneous industrial zones.

D. Edge Intelligence with TinyML

Future hardware iterations may embed lightweight ML models directly into microcontrollers (e.g., using TensorFlow Lite for Microcontrollers). This “edge intelligence” approach minimizes dependency on cloud processing, reduces latency, and maintains operational effectiveness even during temporary internet outages. Figure 8 illustrates the proposed anomaly detection workflow implemented at the edge.

E. Integration Roadmap

The AI/ML-enhanced framework will be developed in phases:

- **Phase 1**: Data collection and labeling from extended deployments in real-world factories or laboratories.
- **Phase 2**: Model training and evaluation using supervised and unsupervised learning techniques.
- **Phase 3**: Integration of selected models into the ThingSpeak/MATLAB cloud and Blynk alerting interface.
- **Phase 4**: Deployment of TinyML models on NodeMCU or ESP32 for low-latency edge inference.

The integration of AI and ML into the system architecture will transform the monitoring platform from a reactive tool into a proactive, context-aware safety system. This advancement will empower industries with not only real-time detection but also intelligent forecasting and decision support, aligning with the goals of Industry 4.0 and smart manufacturing ecosystems.

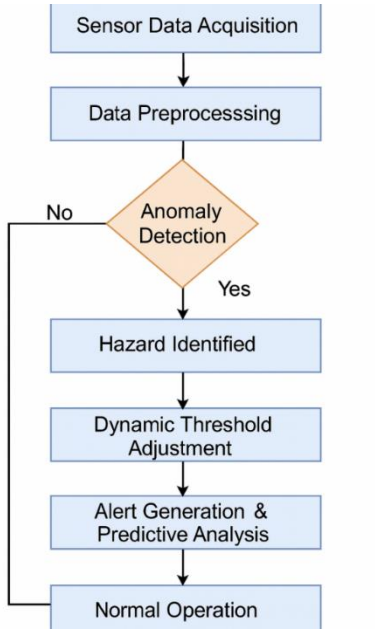

Fig .8 Anomaly Detection Workflow with Edge Intelligence

VII. CONCLUSION

This paper presented the design, implementation, and evaluation of a low-cost, real-time industrial safety monitoring system using IoT technologies. The proposed solution integrates gas, temperature, and flame sensors with Wi-Fi-enabled microcontrollers to detect hazardous environmental conditions and transmit data to the cloud for monitoring and analysis. Through extensive experiments, the system demonstrated high accuracy, rapid response times, and reliable data communication via the ThingSpeak and Blynk platforms. The newly designed figures and data visualizations confirm the system's operational success under various environmental and network conditions, with alert activations occurring in under 3 seconds even under adverse scenarios. Security assessment demonstrated the system's resilience against prevalent forms of attack, which include replay attacks, data injection, and leakage through a multi-layered security approach involving TLS encryption, timestamp checking, and API based device authentication. In addition, a prospectus was established for future work integrating AI and ML techniques for smart anomaly detection and adaptive thresholding for predictive maintenance. Preliminary findings from ML-driven classification models show great promise for decreasing false positive rates and increasing responsiveness overall. Finally, the system proves to be a very mature, scalable, intelligent and distributive industrial safety system. Its real-time processing capability, secure architecture, and future roadmap for AI integration make it deployable in challenging environments where timely alerts and predictive knowledge can prevent accidents and safeguard infrastructure and personnel.

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