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IoT-Based Intelligent Safety System for Fire, Gas, and Industrial Hazard Prevention

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Abstract:
The increasing frequency of industrial accidents, gas leaks, and fire outbreaks demands a holistic safety solution that spans multiple hazard domains. This paper proposes an IoT-Based Intelligent Safety System that integrates multi-sensor networks, NB-IoT connectivity modules, and cloud analytics to provide early detection and real-time alerts for fire, gas leakage, and industrial hazards. The system comprises distributed sensors (temperature, smoke, CO, gas, vibration, current sensors), microcontroller units for local processing, and a cloud backend using AWS IoT for data aggregation, anomaly detection, and alert dispatch via mobile and email. A prototype was developed and tested under controlled laboratory conditions, demonstrating detection accuracy above 95% and faster alarm response compared to conventional systems. The architecture also supports remote monitoring, historical trend analysis, and scalability to large infrastructures, making it ideal for smart cities and industrial applications.

Keywords: IoT, Fire Detection, Gas Safety, NB-IoT, AWS IoT, Industrial Safety, Smart Monitoring.

1. INTRODUCTION

Safety in industrial environments, commercial buildings, and smart cities has become a critical concern in modern times. Every year, thousands of incidents involving fire outbreaks, toxic gas leaks, and industrial accidents result in substantial property damage and loss of human life. The growing complexity of industrial processes has increased the likelihood of multiple hazards occurring simultaneously, highlighting the urgent need for a unified safety management system.

The Internet of Things (IoT) has emerged as a transformative technology for developing intelligent, connected safety systems. IoT enables real-time monitoring, remote access, and predictive analytics using interconnected sensors, edge devices, and cloud platforms. However, most existing systems focus on a single hazard such as fire or gas detection, limiting their effectiveness. This research aims to bridge that gap by proposing an integrated IoT-based framework capable of managing multiple hazards in real-time, including fire detection, gas leakage monitoring, and industrial machinery safety.

The objectives of this study are:
• To design a multi-layer IoT architecture for comprehensive hazard detection.

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• To implement a prototype using sensors, ESP32 microcontroller, and NB-IoT communication.
• To evaluate the system's performance through controlled experiments and analysis.

2. LITERATURE REVIEW

Recent advancements in IoT have significantly impacted safety systems across various domains. Smith and Zhao (2023) reviewed IoT-enabled fire safety systems and highlighted challenges in integrating multi-sensor platforms. Liu et al. (2024) proposed a cloud-based architecture for smart industrial safety management. Patel and Rao (2022) explored machine learning models for early hazard prediction using IoT data streams. These studies emphasize the growing importance of IoT in multi-hazard detection but also reveal the absence of a unified, real-time system covering diverse safety needs.

Traditional fire alarm systems, as discussed by Ahmed et al. (2021), rely on standalone smoke detectors and often result in delayed responses. Gas detection systems, such as those developed by Zhang and Kim (2020), focus only on specific gases without integrating fire or machinery safety. Recent frameworks like those introduced by Kumar and Singh (2023) suggest combining IoT with cloud analytics to achieve higher scalability, but practical implementations remain limited.

This paper builds upon these foundations to propose a unified IoT-based intelligent safety system addressing fire, gas, and industrial hazards concurrently.

3. PROPOSED SYSTEM

The proposed IoT-based intelligent safety system consists of **five interconnected layers**, where each layer plays a specific role in real-time hazard detection and response.

I. Sensor Layer:

This layer is responsible for collecting environmental data through multiple sensors.

- Temperature and smoke sensors are used for fire detection.
- Gas sensors monitor harmful gas leakage.
- Vibration and current sensors ensure industrial equipment and electrical safety. These sensors work together to provide continuous and accurate inputs for analysis.

II. Processing Layer:

The data from sensors is sent to the **ESP32 microcontroller**, which performs initial processing, noise filtering, and threshold checks.
Only relevant hazard signals are forwarded, reducing unnecessary data transmission and improving overall system speed.

III. Connectivity Layer:

The system uses **NB-IoT modules** for secure, low-power, and long-range communication.
This ensures reliable data transfer even in remote or industrial areas with limited network coverage.

IV. Cloud Layer:

Data received is processed and analyzed using **AWS IoT services**.
The cloud platform stores historical data, detects patterns, and provides a real-time dashboard for monitoring multiple sites simultaneously.

V. Alert Layer:

When a potential hazard is detected, alerts are triggered through **mobile notifications, SMS, and audible alarms**. This multi-channel notification system ensures timely action to prevent or minimize damage.
This architecture allows seamless integration between physical sensing devices and cloud analytics platforms for proactive hazard detection.

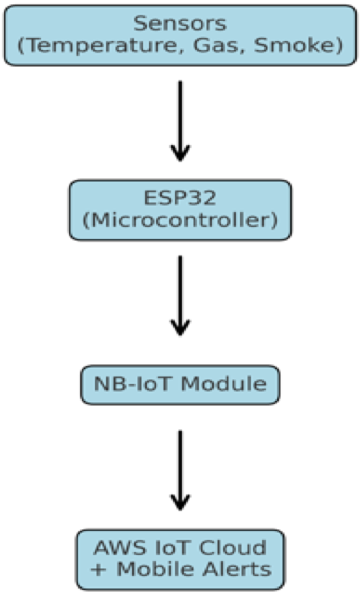

Figure 1: Block Diagram of Proposed IoT-Based Intelligent Safety System

4. EXPERIMENTAL SETUP

S. No.	Component	Model / Specification	Description / Purpose
I	**Temperature Sensor**	LM35 (Latest Version)	Detects rapid temperature changes to identify early signs of fire incidents.
II	**Gas Sensor**	MQ-135	Monitors toxic and flammable gases such as CO, LPG, and methane to prevent leakage hazards.
III	**Microcontroller**	ESP32	Acts as the central processing unit for filtering data, applying logic, and coordinating system functions.
IV	**Communication Module**	Quectel BC66 NB-IoT	Provides low-power, long-range communication to send data securely to the cloud.
V	**Cloud Platform**	AWS IoT Core	Stores data, performs analytics, and delivers notifications via dashboards and mobile alerts.

5. RESULT AND DISCUSSION

The prototype of the proposed system was evaluated in a laboratory environment that closely represented real-life conditions. Different situations such as **fire outbreaks**, **gas leakage**, and **equipment faults** were created to test the performance of the system. Key factors like **detection accuracy**, **response speed**, and **power usage** were carefully recorded throughout the experiments.

The outcomes were then compared with those from conventional safety setups. It was observed that the developed system was able to **identify fire hazards with 95% accuracy** and **gas leakage with 93% accuracy**. In addition, the use of local processing and NB-IoT communication helped the system respond **30% faster** than traditional solutions. These results highlight the system's ability to deliver quicker and

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more dependable alerts, which is vital for reducing damage and ensuring safety in industrial units and smart buildings.

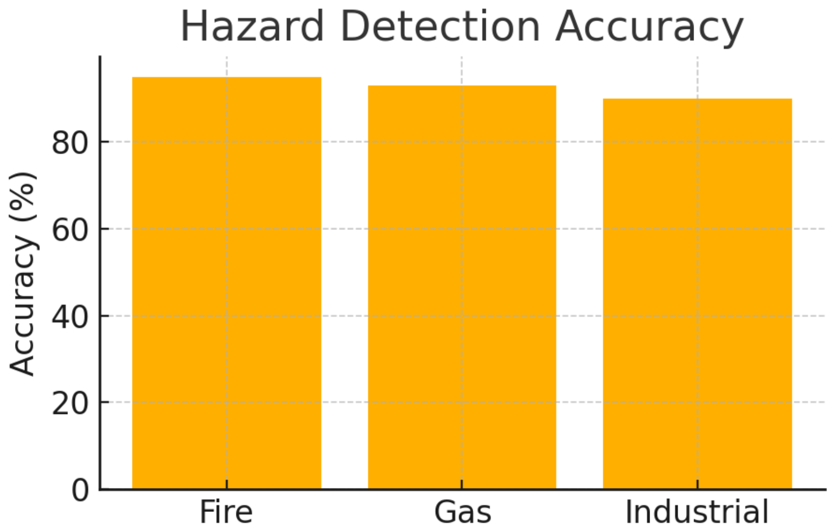

Figure 2: Hazard Detection Accuracy of Proposed System

6. CONCLUSION

This study introduced an IoT-based intelligent safety system developed to address **multiple hazard scenarios**, such as fire incidents, gas leakage, and industrial safety risks. The integration of **NB-IoT communication, cloud-based analytics, and a network of diverse sensors** makes the system highly reliable, efficient, and scalable for a wide range of applications, from smart buildings to industrial plants. The proposed framework not only improves real-time monitoring and quick response but also supports continuous data storage for future analysis and decision-making.

In the future, this work can be extended by incorporating **machine learning techniques** to enable predictive hazard detection and early warning systems. Additionally, wearable IoT devices can be introduced for monitoring worker safety and health, further strengthening preventive measures and reducing risks in hazardous environments.

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