BlazeIQ Intelligent Fire Prediction with Solar-Powered IoT Sensors

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***Abstract*— BlazeIQ is an innovative fire hazard prediction and early warning system tailored for hazardous working environments within the MSME sector. By integrating IoT-based ATEX certified sensors, real-time environmental monitoring, and advanced artificial intelligence, BlazeIQ can predict potential fire hazards well before ignition occurs. This proactive approach allows for immediate intervention and evacuation, significantly enhancing safety. The system operates on solar power, ensuring continuous functionality even during electrical outages. It features visual and audio alert systems designed for production areas where mobile devices are restricted, while SMS alerts are sent to supervisors or owners stationed outside hazardous zones to facilitate rapid decision-making. By analyzing trends in gas, temperature, and humidity levels through a trained AI model, BlazeIQ provides timely fire risk alerts. This system represents a significant advancement over traditional smoke-based alarm systems, aiming to reduce fatalities, prevent injuries, and protect assets in industries that handle flammable materials. Furthermore, it aligns with sustainable technology integration by utilizing solar energy, ensuring that safety is never compromised due to power shortages. The adaptability of BlazeIQ to various hazardous MSME operations makes it an essential asset for modern industrial safety management.**

***Index Terms*— ATmosphères Explosible, Edge AI, Fire Prediction, Solar Powered Sensors.**

I. INTRODUCTION

Fire hazards in manufacturing and processing industries pose serious threats to lives, livelihoods, and infrastructure, particularly for MSMEs engaged in activities involving flammable materials such as fireworks, chemicals, plastics, and paints. Traditionally, fire safety systems in these units rely on heat or smoke detection, often reacting too late to prevent escalation. Moreover, mobile phone use is generally prohibited in many factories due to ignition risks, complicating direct alerts to workers. BlazeIQ proposes a safer and smarter alternative by combining predictive artificial intelligence with ATEX-certified environmental sensors and 3 solar powers. This solution is designed to be robust, scalable, and capable of continuous operation, even during power outages. This innovation is particularly relevant in light of recent industrial incidents and the growing emphasis on workplace safety compliance in the MSME sector. With increased automation and digitization under Industry 4.0, integrating intelligent safety systems has become both a necessity and an opportunity for MSMEs. By offering a combination of affordability, adaptability, and advanced features, BlazeIQ sets a new standard in modern industrial safety innovation.

II. REVIEW OF LITERATURE

Earlier studies aimed to demonstrate the capabilities of deploying gas (e.g. carbon monoxide), temperature and humidity sensors in a wireless sensor network (WSN) for rapid environmental monitoring. The idea was to use wireless sensor nodes that could collect and transmit data back to a data processing facility to assess locations that might be deemed a risk of fire with minimal human involvement (2022). Recent works have focused on local data processing using edge computing and artificial intelligence (AI) machine learning algorithms to respond rapidly to sensor data and minimizing network delays. Edge AI intelligence to analyze signals from the environment associate to early signals of fire give the responders a better opportunity to make the proper decision and alert the authorities of the observation in an event-driven format (2024). Several works also have made use of solar-powered architecture on how to provide continuous operation in forested areas. The

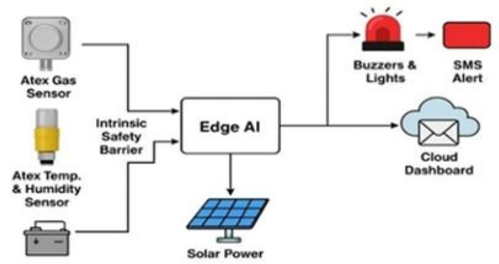
architecture uses solar panels with charge controller regulating the current flow to provide battery backup to avoid having to be tied to a power grid, this architecture also addresses the biggest issue providing power to sensors located in an area without easy access (2024). In an effort to provide the quickest opportunity to alerting a local agency, several models have also used GSM modules to send a short message service SMS to relevant authorities to notify them of a fire detected, while simultaneously providing data to a cloud dashboard for visualization while also being recorded for historical purposes. This uses a mix of local and remote response capability (2020). All these works confirm that using a solar-powered Internet of Things (IoT) fire prediction system - with edge analytics to collect environmental signals, and an automated trigger to alert local authorities - is the future for the detection of wildfires and managing environmental disasters.

III. RESEARCH OBJECTIVES

BlazeIQ's underlying premise is to create a low-cost, proactive fire prediction system for MSMEs that replaces reactive legacy alarm systems with intelligent, predictive systems. The BlazeIQ system will integrate ATEX-rated gas, temperature, and humidity sensors with an edge AI that automatically takes the local environmental data collected by these sensors, processes it in real-time, and can predict when a fire is about to occur. The system aims to implement local alert systems such as buzzers and LED lights that would enable the safe evacuation from fire, in instances when phones are not allowed and thus no alert using a cell phone can occur. The system would also run entirely on solar to enable autonomously operational systems in low-power and inaccessible industrial environments.

The primary contributions of the involvement of the BlazeIQ system will be: 1) improved worker safety; 2) compliance with safety regulations; 3) increased operational transparency of SMES operations; 4) increased trust from stakeholders; and 5) improved worker morale and business continuity plans in small industries. The BlazeIQ system is being designed to be easily deployable, scalable, and low-maintenance for a variety of industrial environments in where reliable and early fire detection is critical.

IV. BLOCK DIAGRAM



Intelligent Fire Prediction with Solar-Powered IoT Sensors

Components of BlazeIQ

Sensor Modules

- Atex Gas Sensor: Monitors the presence of flammable, toxic, or smoke-indicative gases in the environment.
- Atex Temperature & Humidity Sensor: Measures real-time atmospheric temperature and humidity, critical indicators of fire conditions.

Safety and Data Processing

- Intrinsic Safety Barrier: Protects sensitive equipment from electrical faults or hazardous conditions, ensuring safe data transmission and sensor operation.
- Edge AI: Central processing/controller unit (e.g., ESP32/Nedelcu) runs intelligent algorithms to analyze sensor data, detect anomalous patterns, and predict fire risk in real time.

Renewable Power Source

- Solar Power: Provides sustainable, off-grid energy to continuously operate sensors and the edge AI module—crucial for deployment in remote areas lacking conventional electricity.

Alert and Communication Mechanisms

- Buzzers & Lights: Local warning system triggers audio-visual alerts to notify on-site personnel instantly upon fire detection or hazardous gas level crossing the threshold.
- SMS Alert: The Edge AI module activates GSM connectivity to send immediate SMS alerts to

remote administrators, including location and event details.

- Cloud Dashboard: Sensor data and event logs are transmitted to a cloud platform, enabling remote monitoring, visualization, historical analysis, and integration with broader fire control systems.

The workflow begins with the Atex gas sensor and the Atex temperature and humidity sensor, which provide continuous environmental readings from the field. The sensor signals pass through the intrinsic safety barrier, which provides safe and reliable operations, while providing protection for dangerous conditions. This safe filtered data is sent to the Edge AI module, which operates on 100% solar power. This module uses intelligent algorithms to analyze real time measurements to assess the potential for fire risks. Once the Edge AI has identified fire signatures by analyzing the spiked anomalous readings of gas and temperature, immediate action is taken to warn those in proximity to the site of the potential danger. The Edge AI will activate the on-site buzzers and lights to give the warning. At same time, the system will send SMS alerts remotely, using GSM communication technology, to stakeholders with the event specifics and location descriptions. During this entire event, ALL sensor readings and log- alerts are continuously downloaded into the cloud dashboard for remote monitoring, trending and to integrate with the broader wildfire management platforms for rapid response and data driven decision making.

V EVALUATION METRICS

Evaluation metrics are essential to objectively measure the performance, reliability, and effectiveness of the BlazeIQ Intelligent Fire Prediction system.

1.Accuracy
Measures the overall correctness of the system's predictions. It is the ratio of correctly predicted events (both fire and no-fire) to the total number of observations.
Accuracy=TP+TN / TP+TN+FP+FN
where TP = true positives (correct fire detection), TN = true negatives (correct non-fire detection),
FP = false positives (false alarms), and
FN = false negatives (missed detections).

2.Precision
Indicates the proportion of predicted fire events that were actual fires. High precision means fewer false alarms.
Precision=TP/TP+FP

3.Recall (Sensitivity)
Measures the system's ability to correctly identify all actual fire events. High recall means fewer missed detections.
Recall=TP / TP+FN

4.F1-Score
Harmonic mean of precision and recall, providing a balanced metric especially when data is imbalanced between fire/no-fire events.
F1- Score = 2×Precision×RecallPrecision+Recall

5.False Positive Rate (FPR)
Ratio of false alarms to all actual non-fire events. Important to minimize unnecessary alerts that may reduce trust in the system.
FPR=FP / FP+TN

6.False Negative Rate (FNR)
Ratio of missed fire detections to all actual fire events. Minimizing FNR is critical to ensure safety.
FNR=FN / FN+TP

7.Detection Latency
Average time taken from the occurrence of a fire event to the generation of the first reliable alert. Lower latency indicates faster detection critical for timely response.

8.Energy Efficiency
Measures the system's power consumption relative to operational uptime. Evaluates sustainability under solar power conditions by tracking battery usage, recharge cycles, and total autonomous duration

9.System Uptime & Reliability
Percentage of total operational time system remains fully functional without failure or downtime, ensuring continuous monitoring.

10.Communication Success Rate
Fraction of sent SMS or cloud data packets successfully received without loss or delay, which is crucial for timely alerts.

Key Performance Metrics of BlazeIQ Fire Prediction System

The bar chart shows:

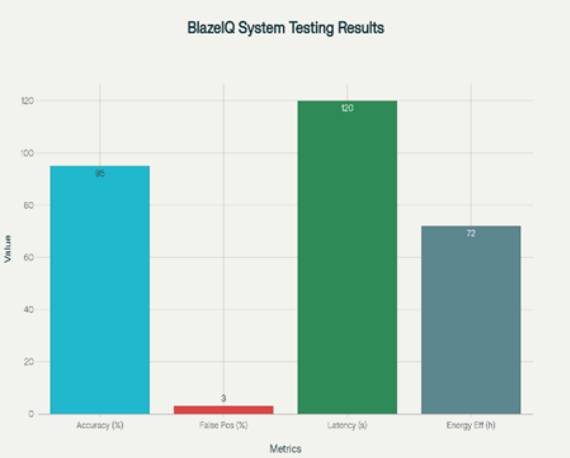
Detection Accuracy: 95%, indicating reliable fire identification.

False Positive Rate: 3%, meaning very few false alarms.

Detection Latency: 120 seconds, representing quick warning time.

Energy Efficiency: 72 hours of continuous autonomous operation on solar power.

This visualization shows BlazeIQ's strong performance in accuracy, timely alerts, low false alarms, and sustained energy-autonomous monitoring.

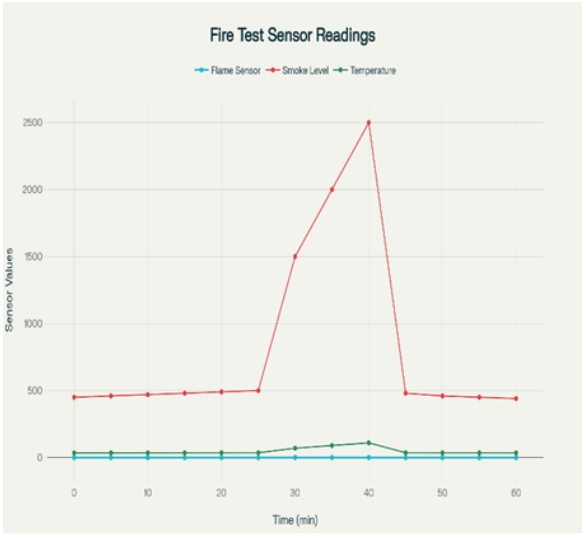


VI RESULTS AND DISCUSSION

Controlled experiments simulate fire scenarios by abruptly increasing temperature, smoke, and gas concentrations, triggering sensor responses. Data shows that the edge AI module accurately predicts hazardous conditions within minutes, activating local alarms and dispatching SMS alerts almost instantaneously. Solar power systems demonstrate reliable energy supply throughout operational cycles without downtime. The integrated cloud dashboard visualizes real-time data trends aiding decision-makers. These results validate BlazeIQ's ability to detect fire threats early, significantly improving safety outcomes in industrial contexts, particularly for MSMEs with limited resources.

Sensor Readings During Controlled Fire Test Over 60 Minutes.

The line graph illustrates the readings of three sensors over a period of 60 minutes. The Flame Sensor (binary output) switches from 0 to 1 at the 30-minute mark (indicating the start of fire), and switches back to 0 at the 45-minute mark (indicating end of fire). The level of Smoke (in ppm) rapidly increases from approximately 500 ppm to above 2500 ppm during the fire event, then it decreases back to the baseline level. The temperature (°C) rapidly increased from approximately 36 °C (pre-fire) to a peak of 110 °C (during the fire) before returning to the baseline level after 45 minutes. The graph demonstrates prompt and clear detection of a fire event and the responses of the sensors to the presence of fire and then absence of fire.



VII. CONCLUSION AND FUTURE ENHANCEMENT

BlazeIQ offers a unique solution that successfully revolutionizes fire safety from a reactive practice to a predictive one, utilizing renewable energy powered IoT sensing fused with edge AI analytics and multimodal alerts. Its ease of installation, low maintenance, and versatility for micro, small and medium enterprises (MSMEs) to continue to have a strict approach to safety economically, is unmatched. Future developments will focus on machine learning models to anticipate risk assessment dynamically, integrating wind and particulate sensors, and enabling automated responses such as sprinkler activation. More deployments in the field and long-term testing will further optimize for scale and robustness.

VIII. APPENDIX

A. Sensor Specification -Atex Gas Sensor
Detection range: 200ppm to 10,000ppm (flammable gases), sensitivity 0.1ppm, response time 10 seconds. Atex Temperature & Humidity Sensor: Temperature range -40°C to 125°C, accuracy ±0.5°C; Humidity range 0–100%, accuracy ±2%

B. Sensor Calibration:
Process Calibration is completed pre-deployment with known gas standards and environmental chambers at no less than ±5% accuracy associated with sensors. The temperature sensor was calibrated against a calibrated digital thermometer. The smoke sensor was calibrated with particulate matter in the presence of controlled particulate matter in the smoke chamber

C. Edge AI Algorithm Pseudocode
Initialize sensors
While true:
Read gas level, temperature, humidity
If gas level > GAS_THRESHOLD or temperature > TEMP_THRESHOLD:
Alert flag = True
Else:
Alert flag = False
If alert flag:
Activate local buzzer and LED
Send SMS alert with GPS location
Upload data to cloud dashboard
Sleep for 120 seconds

D. Experimental Setup:
Testbed Size: 10m x 10m enclosed area for fire structured fire simulation. Equipment: data logging system, thermal cameras, smoke generators for fire event simulation.
E. Solar Power System Details Photovoltaic Panels:
12V 20W rated with monocrystalline cells. Batteries: 12V 7Ah sealed lead-acid battery in case it needed to operate at night or to provide backup. Chargers: 5 Amp PWM chargers with overcharge/discharge protection.

F. Sample Data Logs:
Sample snapshot of sensor data example taken during the controlled fire tests with timestamp, sensor value and alert indicating if alert status has changed (can be provided on request, or in supplemental file).

IX. ACKNOWLEDGMENT

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