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IOT - Enabled Fire Detection And Risk Prediction Using ML

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ABSTRACT

Fire incidents in residential, commercial, and industrial environments can lead to severe loss of life, property damage, and environmental harm if not detected at an early stage. Conventional fire alarm systems primarily respond only after fire or smoke reaches a predefined threshold, often resulting in delayed emergency response. To overcome these limitations, this study proposes an IoT-Enabled Fire Detection and Risk Prediction System Using Machine Learning, which integrates real-time sensor monitoring with intelligent predictive analytics. The proposed system employs Internet of Things (IoT) devices equipped with temperature, smoke, gas, flame, and humidity sensors to continuously collect environmental data. The sensed information is transmitted to a cloud platform for storage, monitoring, and analysis. Machine learning algorithms are utilized to analyze historical and real-time sensor readings to predict the probability of fire occurrence before it becomes critical. By identifying abnormal environmental patterns and classifying risk levels, the system generates early warnings and sends instant alerts to users and emergency authorities through mobile or web-based applications. This proactive approach enables timely preventive actions, minimizes false alarms, and enhances overall safety. Furthermore, cloud-based data storage supports continuous learning and improves prediction accuracy over time. The proposed framework offers a scalable, cost-effective, and reliable solution for smart buildings, industrial facilities, warehouses, and public infrastructures. Experimental evaluation demonstrates that the integration of IoT and machine learning significantly improves fire detection accuracy, reduces response time, and enhances risk prediction compared to traditional fire alarm systems. This intelligent fire safety solution contributes to the development of smart cities by providing continuous monitoring, predictive decision-making, and efficient emergency management.

Keywords: Internet of Things (IoT), Fire Detection, Machine Learning, Risk Prediction, Smart Sensors, Environmental Monitoring, Early Warning System, Predictive Analytics, Cloud Computing, Smart Safety Systems.

I. INTRODUCTION

Fire accidents remain one of the leading causes of loss of life, infrastructure damage, and economic disruption across residential, commercial, and industrial environments. Rapid urbanization, increasing energy consumption, and the widespread use of electrical and combustible materials have significantly increased the risk of fire incidents. Conventional fire detection systems mainly rely on smoke or heat sensors that trigger alarms only after predefined threshold values are reached. Although these systems provide basic protection, they often fail to detect hazardous conditions at an early stage and are unable to predict potential fire risks. As a result, delayed alerts can lead to extensive damage and reduced opportunities for effective emergency response.

The emergence of the Internet of Things (IoT) has transformed safety monitoring by enabling continuous collection and transmission of real-time environmental data through interconnected smart devices. IoT-based fire detection systems utilize sensors such as temperature, smoke, gas, flame, and humidity sensors to monitor environmental conditions continuously. These sensors communicate with cloud platforms or edge devices, allowing users to access live monitoring information from remote locations. However, IoT-based monitoring alone is primarily reactive, as it focuses on detecting existing hazardous conditions rather than predicting future fire events.

Recent advancements in Machine Learning (ML) provide an opportunity to enhance fire safety by enabling intelligent prediction and risk assessment. Machine learning algorithms can analyze large volumes of historical and real-time sensor data to identify hidden patterns associated with fire hazards. By learning from previous incidents, ML models can classify environmental conditions into different risk categories and estimate the likelihood of fire occurrence before an actual outbreak. This

predictive capability supports early intervention, reduces false alarms, and enables more effective emergency preparedness.

The proposed IoT-Enabled Fire Detection and Risk Prediction Using Machine Learning system integrates IoT sensing technology with machine learning algorithms to create an intelligent fire monitoring framework. Environmental data collected from multiple sensors are transmitted to a cloud platform, where they undergo preprocessing, feature extraction, and predictive analysis. Based on the analyzed data, the system categorizes fire risk levels and generates real-time alerts through web or mobile applications whenever abnormal conditions are detected. This integration improves the speed, accuracy, and reliability of fire detection while supporting remote monitoring and automated decision-making.

The proposed framework is suitable for deployment in smart homes, industrial plants, warehouses, educational institutions, hospitals, shopping malls, and public infrastructure. Its scalable architecture enables continuous monitoring, efficient data management, and adaptive learning as additional sensor data become available. By combining IoT connectivity with machine learning-based predictive analytics, the system provides a proactive approach to fire prevention, helping reduce property loss, protect human lives, and improve overall public safety. This research contributes to the advancement of intelligent safety systems and supports the development of safer and more resilient smart city environments.

II. LITERATURE SURVEY

1. Title: IoT-Based Smart Fire Detection and Notification System

Authors: A. Sharma, R. Verma, and S. Gupta

Abstract:

The authors proposed an Internet of Things (IoT)-based fire detection system that continuously monitors environmental parameters using smoke, temperature, and flame sensors. The collected sensor data are transmitted to a cloud platform through Wi-Fi, enabling real-time monitoring and instant alert notifications via mobile devices. Experimental results demonstrated that the system significantly reduced response time compared to conventional fire alarm systems. However, the proposed solution focused only on real-time detection and did not include predictive analytics for assessing future fire risks.

2. Title: Machine Learning-Based Fire Risk Prediction Using Environmental Sensor Data

Authors: J. Kim, H. Lee, and M. Park

Abstract:

This study developed a machine learning framework to predict fire risk by analyzing historical environmental sensor readings. Various classification algorithms, including Random Forest, Decision Tree, and Support Vector Machine, were evaluated to classify fire risk levels. The Random Forest model achieved the highest prediction accuracy and demonstrated effective early risk assessment. Although the system improved prediction performance, it lacked integration with IoT devices for continuous real-time monitoring.

3. Title: An Intelligent Fire Monitoring System Using IoT and Cloud Computing

Authors: P. Kumar, N. Singh, and R. Mishra

Abstract:

This research presented an intelligent fire monitoring architecture that combines IoT sensors with cloud computing services for continuous environmental surveillance. Temperature, gas, smoke, and humidity sensors transmitted real-time information to a cloud server for storage and visualization.

The system successfully provided remote monitoring and emergency alerts. However, the proposed architecture relied on threshold-based detection methods and did not employ machine learning techniques to predict fire occurrence.

4. Title: Early Fire Detection Using Deep Learning and Sensor Networks

Authors: L. Wang, Y. Chen, and X. Zhao

Abstract:

The authors introduced a deep learning-based fire detection model that utilized sensor network data to identify fire-related patterns. A neural network model was trained using environmental datasets to distinguish between normal and hazardous conditions. Experimental evaluation showed improved detection accuracy and lower false alarm rates compared to traditional rule-based systems. Nevertheless, the computational complexity of the model limited its deployment on low-power IoT devices.

5. Title: Hybrid IoT and Machine Learning Framework for Smart Fire Safety Applications

Authors: S. Patel, K. Shah, and D. Joshi

Abstract:

This paper proposed a hybrid framework integrating IoT technology with machine learning algorithms for intelligent fire safety management. Multiple environmental sensors collected real-time data, while Gradient Boosting and Random Forest algorithms predicted fire risk levels. The framework generated early warning alerts through cloud-based applications and demonstrated higher prediction accuracy than conventional fire detection systems. The study concluded that integrating IoT with machine learning significantly enhances fire prevention capabilities and supports the development of smart safety infrastructures.

III. EXISTING SYSTEM

Existing fire detection systems primarily rely on conventional smoke detectors, heat sensors, and flame detectors to identify fire incidents after hazardous conditions have already developed. These systems operate using predefined threshold values, where an alarm is activated only when the measured temperature, smoke concentration, or flame intensity exceeds a fixed limit. While such systems provide basic fire protection, they often detect fires only after they have reached a dangerous stage, reducing the available response time for evacuation and emergency intervention.

With the advancement of the Internet of Things (IoT), several smart fire monitoring systems have been introduced to improve real-time surveillance. These systems use multiple environmental sensors connected through wireless communication technologies to continuously monitor temperature, humidity, smoke, gas, and flame levels. The collected data are transmitted to cloud servers or mobile applications, allowing users to remotely monitor environmental conditions and receive instant notifications whenever abnormal sensor readings are detected. Although these systems enhance accessibility and remote monitoring, they still depend largely on fixed threshold values for decision-making.

Some recent research has incorporated machine learning techniques to improve fire detection by analyzing historical sensor data and classifying fire-related events. These models can identify complex relationships among environmental parameters and reduce false alarms compared to traditional threshold-based methods. However, many of these machine learning approaches are developed using offline datasets and are not integrated with real-time IoT sensor networks. As a result, they cannot provide continuous monitoring or immediate predictive alerts in practical environments. Furthermore, existing systems often face challenges such as delayed detection, high false alarm rates, limited scalability, and insufficient predictive capabilities. Many solutions are designed only to detect ongoing fire incidents rather than forecast potential fire risks before ignition occurs.

The absence of intelligent risk prediction, adaptive learning, and comprehensive cloud-based analytics limits the effectiveness of conventional and standalone IoT fire detection systems. These limitations highlight the need for an integrated solution that combines real-time IoT monitoring with machine learning-based fire risk prediction to enable proactive fire prevention and faster emergency response.

IV. PROPOSED SYSTEM

The proposed IoT-Enabled Fire Detection and Risk Prediction Using Machine Learning system integrates Internet of Things (IoT) technology, cloud computing, and machine learning to provide an intelligent and proactive fire safety solution. Unlike conventional fire alarm systems that react only after hazardous conditions are detected, the proposed framework continuously monitors environmental parameters and predicts potential fire risks before they become critical. The system employs multiple IoT sensors, including temperature, smoke, gas, flame, and humidity sensors, to collect real-time environmental data from the monitored location. These sensor readings are transmitted through a wireless communication network to a cloud platform for storage and analysis.

After data collection, the sensor information undergoes preprocessing to remove noise, handle missing values, and normalize the dataset for accurate analysis. Machine learning algorithms such as Random Forest, Decision Tree, Support Vector Machine (SVM), or Extreme Gradient Boosting (XGBoost) are trained using historical and real-time sensor data to classify environmental conditions into different fire risk levels. The trained model continuously evaluates incoming sensor readings, detects abnormal patterns, and predicts the probability of fire occurrence with higher accuracy than traditional threshold-based approaches.

When the predicted fire risk exceeds a predefined safety level, the system immediately generates alerts and sends notifications to users, building administrators, and emergency response teams through mobile applications, web dashboards, SMS, or email services. The cloud platform maintains historical sensor data, prediction results, and system logs, enabling continuous monitoring, performance analysis, and future model improvements. A user-friendly dashboard provides real-time visualization of sensor values, fire risk levels, alert history, and device status, allowing users to monitor the environment remotely from any location.

The proposed system offers several advantages, including early fire risk prediction, reduced false alarms, faster emergency response, continuous remote monitoring, and scalable deployment across residential buildings, industries, warehouses, hospitals, educational institutions, and smart city infrastructures. By combining IoT-enabled sensing with machine learning-based predictive analytics, the framework enhances fire prevention capabilities, improves public safety, and supports intelligent decision-making. This integrated approach provides a reliable, cost-effective, and scalable solution for next-generation smart fire safety management systems.

V. SYSTEM ARCHITECTURE

The proposed IoT-Enabled Fire Detection and Risk Prediction Using Machine Learning system is designed to detect fire hazards at an early stage and estimate the associated risk level using real-time environmental data. The architecture consists of multiple interconnected layers that work together to collect sensor readings, process data, apply machine learning algorithms, and generate timely alerts for users and emergency services.

The IoT Sensing Layer forms the foundation of the system. It consists of several environmental sensors, including temperature, smoke, flame, humidity, carbon monoxide (CO), and gas sensors,

along with an optional GPS module for location tracking. These sensors continuously monitor the surrounding environment and collect real-time data related to fire conditions. Any abnormal increase in temperature, smoke concentration, or gas levels is immediately captured and forwarded for further processing. This layer ensures continuous environmental monitoring and provides accurate input data for fire detection.

The collected sensor data is transmitted to the IoT Gateway Layer, which acts as an intermediate communication unit between the sensing devices and the cloud platform. A microcontroller or gateway device such as ESP32, Arduino, or Raspberry Pi aggregates data from multiple sensors, filters out noise, timestamps the readings, and securely transmits the processed information using wireless communication technologies such as Wi-Fi, ZigBee, or LoRa. This layer improves data reliability while reducing communication delays and ensuring secure data transfer.

After transmission, the data reaches the Cloud/IoT Platform Layer, where it is stored in a centralized cloud database. Cloud platforms such as AWS IoT, Firebase, or ThingsBoard manage real-time data storage, device management, and large-scale data processing. Historical sensor readings are maintained in the database, allowing continuous monitoring and providing sufficient training data for machine learning models. The cloud infrastructure enables remote accessibility, scalability, and efficient handling of large volumes of sensor information.

The Machine Learning Processing Layer is responsible for analyzing the incoming sensor data and predicting fire-related events. A trained machine learning model processes the sensor values to classify whether a fire is present or not. Additionally, the model predicts the severity of the situation by categorizing the risk level into Low, Medium, or High. During the training phase, historical sensor datasets undergo preprocessing and feature engineering before algorithms such as Random Forest, XGBoost, Support Vector Machine (SVM), or Artificial Neural

Networks (ANN) are trained. The trained model is then deployed for real-time prediction, enabling accurate and intelligent fire detection.

The prediction results are forwarded to the Alert and Notification Layer, which generates immediate warnings whenever a potential fire hazard is detected. Depending on the predicted risk level, the system activates alarms, buzzers, mobile notifications, SMS messages, emails, and web dashboard alerts. These real-time notifications enable building occupants, administrators, and emergency response teams to take prompt action before the fire spreads, thereby minimizing property damage and protecting human lives.

The final component is the User Layer, which includes different stakeholders such as the fire department, building administrators, and general users. Users can access the web dashboard or mobile application to monitor live sensor values, view predicted risk levels, and receive emergency notifications. The dashboard provides real-time visualization of environmental conditions and system status, enabling efficient monitoring and decision-making from any location with internet connectivity.

To continuously improve system performance, the architecture also incorporates a Feedback and Continuous Improvement Module. User feedback regarding true or false alarms is collected and stored along with newly generated sensor data. This information is used to retrain and optimize the machine learning model periodically, improving prediction accuracy and reducing false positives over time. As more data becomes available, the system becomes increasingly reliable and adaptive to different environmental conditions.

Overall, the proposed architecture integrates IoT sensing, cloud computing, and machine learning into a unified intelligent fire monitoring system. The combination of real-time sensor data acquisition, cloud-based processing, predictive analytics, and instant notification mechanisms enables early fire detection, accurate risk assessment, and rapid emergency response,

making the system highly suitable for smart homes, industries, commercial buildings, warehouses, and public infrastructure.



Fig 5.1: System Architecture

VI. IMPLEMENTATION



Fig 6.1: Dashboard

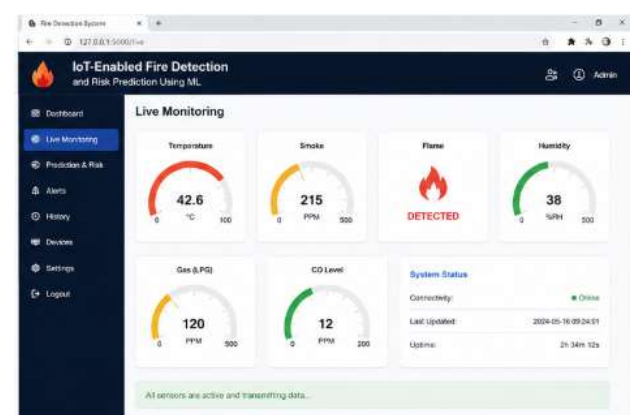


Fig 6.2: Live Monitoring

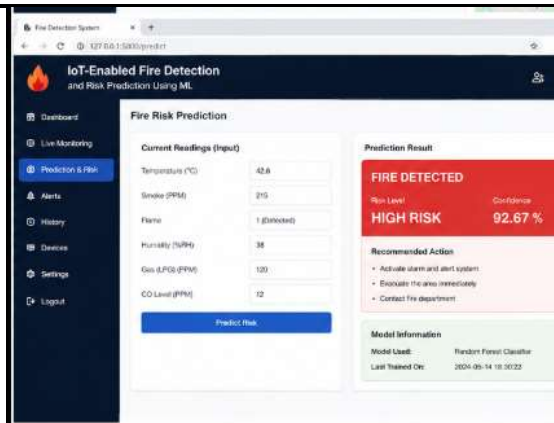


Fig 6.3: Fire Risk Prediction

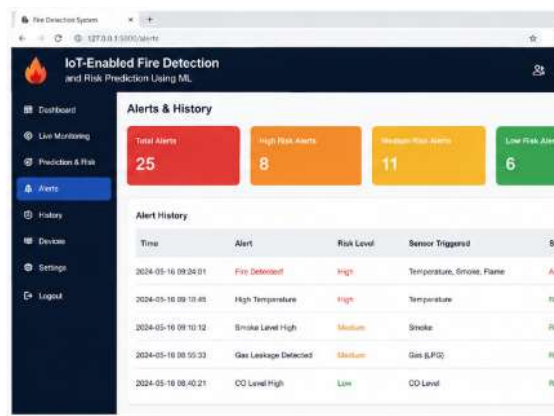


Fig 6.4: Alerts And History

VII. CONCLUSION

The proposed IoT-Enabled Fire Detection and Risk Prediction Using Machine Learning system provides an intelligent and efficient solution for detecting fire incidents at an early stage while accurately predicting the associated risk level. By integrating multiple IoT sensors with cloud computing and machine learning algorithms, the system continuously monitors environmental conditions such as temperature, smoke, flame, humidity, and gas concentration. The collected data is analyzed in real time to identify potential fire hazards and classify the severity of the situation, enabling faster and more reliable decision-making than conventional fire alarm systems.

The use of machine learning significantly improves the accuracy of fire detection by reducing false alarms and adapting to

different environmental conditions through continuous model training. Real-time notifications delivered through mobile applications, web dashboards, alarms, SMS, and email ensure that building occupants, administrators, and emergency responders receive timely warnings, allowing immediate preventive action. This rapid response capability minimizes property damage, reduces the risk to human life, and enhances overall emergency preparedness.

Furthermore, the cloud-based architecture offers scalability, secure data storage, remote monitoring, and centralized device management, making the system suitable for deployment in smart homes, commercial buildings, industries, warehouses, educational institutions, and public infrastructure. The feedback mechanism enables continuous improvement of the prediction model by learning from newly collected sensor data, thereby increasing the system's reliability over time.

In conclusion, the proposed IoT-enabled fire detection and risk prediction framework demonstrates how the integration of IoT technologies and machine learning can transform traditional fire safety systems into intelligent, proactive, and data-driven solutions. The system enhances public safety through early detection, accurate risk assessment, and rapid emergency notification, making it an effective and practical approach for modern fire prevention and disaster management applications.

VIII. FUTURE SCOPE

The proposed IoT-Enabled Fire Detection and Risk Prediction Using Machine Learning system can be further enhanced by incorporating advanced artificial intelligence techniques and a larger network of smart sensors. Future versions of the system can employ deep learning models such as Convolutional Neural Networks (CNNs), Long Short-Term Memory (LSTM) networks, or hybrid AI models to improve prediction accuracy by analyzing complex temporal patterns in environmental data. Training the models with larger and more

diverse datasets collected from different climatic and industrial environments will also improve their robustness and reduce false alarms.

The system can be extended by integrating computer vision using surveillance cameras to detect visible smoke, flames, and abnormal human activities alongside sensor data. Combining image-based fire detection with IoT sensor readings through sensor fusion techniques will provide more reliable and accurate fire identification. Additionally, deploying edge computing devices can enable local processing of sensor data, reducing response time and maintaining system functionality even during internet connectivity failures.

Future implementations may also incorporate autonomous emergency response mechanisms, such as automatically activating sprinkler systems, opening emergency exits, shutting down electrical power, and notifying nearby emergency services without human intervention. Integration with smart building management systems and smart city infrastructure will allow coordinated responses across multiple buildings, improving disaster management in urban environments.

Another promising direction is the use of 5G communication, digital twins, and cloud-edge hybrid architectures for faster data transmission and real-time monitoring. Advanced visualization dashboards with predictive analytics, GIS-based fire mapping, and mobile applications supporting live location tracking can further enhance situational awareness. Moreover, continuous learning techniques and federated learning can enable the machine learning model to improve over time while preserving data privacy across multiple deployment locations.

Overall, the future scope of this project lies in developing a fully autonomous, scalable, and intelligent fire safety ecosystem capable of providing highly accurate fire prediction, rapid emergency response, and seamless

integration with next-generation smart homes, industrial automation systems, and smart city platforms. Such advancements will contribute significantly to reducing fire-related accidents, protecting human lives, and minimizing economic losses.

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