ADVANCED SMOKE DETECTION SYSTEM: INTEGRATING PHOTOELECTRIC SENSOR TECHNOLOGY

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Abstract: *Fire incidents continue to pose significant threats to human life and property. While photoelectric sensors are effective, they frequently generate false alarms from non-combustion aerosols. This study proposes a multi-layered intelligent smoke detection system that integrates photoelectric sensor technology, multi-sensor fusion, edge-based signal processing, and IoT network protocols. The methodology combines dual-wavelength optical scattering (infrared and blue LEDs) with an electrochemical Carbon Monoxide (CO) sensor to verify combustion. Data is processed locally using a lightweight Support Vector Machine (SVM) algorithm to generate a Fire Probability Index (FPI). Expected results indicate the proposed system significantly improves detection accuracy and reduces false alarms compared to conventional fixed-threshold optical detectors. Furthermore, the IoT-based synchronized network enhances situational awareness and accelerates emergency response. In conclusion, the integration of multi-sensor fusion and edge computing provides a robust, scalable solution for modern fire safety applications.*
Keywords: smoke detection, photoelectric sensor, multi-sensor fusion, IoT, edge computing

INTRODUCTION

Fire incidents continue to pose significant threats to human life and property worldwide. According to the National Fire Protection Association (NFPA, 2024), thousands of fire incidents occur annually, resulting in substantial loss of life, injuries, and billions of dollars in property damage. Previous studies have shown that smoke inhalation is responsible for a large proportion of fire-related fatalities because toxic gases and smoke can spread rapidly before flames become visible. Early detection of smoke is therefore essential for reducing casualties and minimizing property damage in residential, commercial, and industrial buildings.

Historically, ionization detectors were widely used due to their sensitivity to fast flaming fires, but studies have shown that they are less effective in detecting smoldering fires, which often produce toxic gases before visible flames appear (Lee, 2015). As a result, photoelectric detectors have become the preferred technology, operating by detecting

light scattering caused by smoke particles within an optical chamber. However, conventional smoke detection systems frequently generate nuisance or false alarms caused by cooking fumes, dust particles, steam, and other indoor aerosols. These false alarms may lead occupants to ignore warnings or disable the detectors.

Despite advancements in smoke detection technology, there remains a research gap in developing intelligent systems that can accurately distinguish dangerous smoke from harmless airborne particles while maintaining rapid response times. Recent studies have explored multi-sensor fusion and intelligent signal processing, but many existing solutions rely heavily on cloud computing, creating potential delays during network disruptions. Therefore, this study proposes an advanced smoke detection system that integrates photoelectric sensor technology with signal processing techniques, multi-sensor fusion, and network-based safety protocols to improve detection accuracy and reliability.

METHOD

To address the limitations of conventional smoke detectors, this study proposes a three-layer architecture consisting of hardware integration, intelligent signal processing, and network-based response protocols.

Hardware Integration and Sensor Fusion: The system employs a photoelectric sensing chamber using dual-wavelength optical scattering with infrared (IR) and blue LEDs to characterize airborne particles. To enhance reliability, the optical sensor is integrated with an electrochemical Carbon Monoxide (CO) sensor. Since CO is a direct byproduct of combustion and is absent in steam or ordinary dust, it serves as an effective secondary verification mechanism to reduce false alarms (Choi et al., 2021).

Edge-Based Intelligent Signal Processing: The system utilizes edge-based processing to analyze sensor information locally without relying on continuous cloud connectivity. Continuous data from the optical and CO sensors are processed by a lightweight Support Vector Machine (SVM) algorithm embedded in the microcontroller. These features are compared with pre-trained datasets representing both real fire scenarios and nuisance sources. Based on this comparison, a Fire Probability Index (FPI) is generated, and an alarm is activated only when the probability exceeds a predefined confidence threshold (Lee, 2016).

Network-Based Safety Protocols: Each detector is connected through an Internet of Things (IoT) network using a low-latency communication protocol such as MQTT. During the pre-alarm stage, when fire probability rises, the system sends an early warning to the building management. Once combustion is confirmed (full-alarm stage), all detectors synchronize to activate

simultaneously while transmitting location-specific information to emergency response services.

RESULTS AND DISCUSSION

The proposed intelligent smoke detection system is expected to achieve higher detection accuracy and lower false alarm rates compared to conventional photoelectric smoke detectors. By combining dual-wavelength optical sensing with Carbon Monoxide (CO) verification, the system can distinguish combustion-generated smoke from non-hazardous airborne particles. Furthermore, the electrochemical CO sensor serves as a secondary validation mechanism, as steam and dust do not produce significant concentrations of CO.

The implementation of the SVM algorithm continuously evaluates multiple parameters (optical scattering intensity, particle accumulation rate, and CO concentration growth) to calculate a Fire Probability Index (FPI). This edge-based machine learning approach is expected to improve decision-making accuracy and ensure continuous real-time operation under varying network conditions.

The implementation of MQTT-based communication enables all detectors to operate as a coordinated safety network, allowing rapid dissemination of warning information throughout the entire building.

Tabel 1. Comparison Between Conventional and Proposed Smoke Detection Systems

Parameter	Conventional Photoelectric Detector	Proposed Intelligent System
Smoke Detection	Optical sensing only	Optical + CO sensing
False Alarm Resistance	Moderate	High
Particle Classification	Limited	Multi-parameter analysis
Decision Method	Fixed threshold	Machine learning (SVM)
Internet Dependency	Not applicable	Edge processing, low dependency
Early Warning Capability	Limited	Pre-alarm notification
Network Integration	Standalone	IoT-based synchronized network

DISCUSION

The proposed system addresses several limitations commonly found in existing smoke detection technologies. The use of multi-sensor fusion enhances detection reliability, while edge-based machine learning enables adaptive decision-making without requiring continuous cloud connectivity. These features collectively contribute to improved fire detection performance and reduced nuisance alarms. The comparison suggests that the proposed architecture offers substantial improvements in reliability, responsiveness, and operational intelligence. However, challenges remain, as the

effectiveness of the SVM classifier depends on the quality and diversity of the training dataset. Future work should include experimental validation using various fire scenarios and explore alternative machine learning algorithms, such as Random Forests or lightweight neural networks, to further improve classification accuracy.

CONCLUSION

Core Summary

This study proposed an intelligent smoke detection system that integrates multi-sensor fusion, edge-based machine learning, and IoT communication to enhance fire detection performance. The proposed architecture addresses the limitations of conventional smoke detectors by improving the ability to differentiate hazardous smoke from non-hazardous airborne particles while maintaining rapid response capabilities. Based on the analysis, the system is expected to achieve higher detection reliability, lower false alarm rates, and more effective emergency response coordination, making it a promising solution for modern fire safety applications. Future research should focus on prototype development, experimental validation, and performance evaluation under various fire and non-fire scenarios to verify its effectiveness.

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