Information Sciences and Technological Innovations

www.isti.reapress.com

Inf. Sci. Technol. Innov. Vol. 1, No. 1 (2024) 19–26.

Paper Type: Original Article

IoT Enabled Real Time Fire Monitoring and Response in Urban Areas

Aadhya Shrivastava[1], Abhinav Gogoi[1], Sharad Shahi[1,*], Sai Chaitanya[1]

[1]School of Computer Science Engineering, KIIT University, Bhubaneshwar, India;
2229001@kiit.ac.in; 2229003@kiit.ac.in; 22052332@kiit.ac.in; 22052332@kiit.ac.in.

Citation:

Received: 10 August 2024 *Revised: 15 October 2024* *Accepted: 26 November 2024*	Shrivastava, A., Gogoi, A., Shahi, Sh., & Chaitanya, S. (2024). *IoT enabled real time fire monitoring and response in urban areas, 1*(1), 19-26.

Abstract

Safety and mitigating potential damage. This study investigates an Internet of Things (IoT)- enabled framework designed for real-time fire monitoring and response, utilizing sophisticated deep learning methodologies. The paper examines the integration of intelligent sensors that continuously gather environmental data, encompassing temperature, smoke, and gas. Levels to promote early fire detection. The proposed system utilizes a deep learning model to accurately classify and predict fire incidents, significantly improving Response Time (RT)s. Furthermore, the architecture incorporates communication protocols that facilitate rapid data transmission to emergency response teams and urban management systems, ensuring timely intervention. Our approach underscores the significance of data fusion from many IoT devices, which enhances situational awareness and decision-making processes during fire emergencies. By addressing critical challenges such as scalability, interoperability, and the reduction of false alarms, this research provides a holistic solution for urban fire safety, ultimately advancing smarter and safer cities.

Keywords: IoT, Deep learning, Fire detection, Urban safety, Real-time monitoring.

1 | Introduction

Urban areas are becoming increasingly susceptible to fire hazards due to their high population density, intricate infrastructure, and varied land use. Conventional fire detection methods frequently encounter difficulties delivering timely alerts and accurate evaluations, which can result in catastrophic repercussions for communities, economies, and the environment. Recent Internet of Things (IoT) advancements present innovative solutions to improve fire monitoring and response capabilities within smart city contexts in light of these challenges. IoT devices, which are outfitted with an array of sensors—including temperature, smoke, and gas detectors—are capable of continuously monitoring environmental conditions and supplying real-time

Corresponding Author: 2229003@kiit.ac.in

data for early fire detection. This capability enables proactive measures to be implemented before the escalation of fires.[1][2].

Incorporating deep learning algorithms into these IoT systems has shown considerable promise in enhancing the accuracy and efficiency of fire detection processes. These algorithms can process data from multiple sensors to identify intricate patterns associated with fire incidents. For instance, Convolutional Neural Networks (CNNs) can be trained to distinguish between fire-related signals and normal environmental fluctuations, thereby reducing false alarms and ensuring that authentic threats receive priority attention [3][4]

Research indicates that such deep learning methodologies can attain notable accuracy in fire detection, which is essential for urban safety and emergency preparedness.[5]

Beyond enhancing detection accuracy, the seamless communication between IoT devices and emergency response systems can significantly decrease Response Time (RTs) during fire incidents. These systems enable swifter interventions and more efficient resource allocation by conveying real-time alerts to firefighters, urban management authorities, and residents [6], [7]. For example, when an IoT sensor identifies abnormal temperature increases or the presence of smoke particles, it can automatically alert nearby fire stations and initiate automated emergency protocols, thereby improving the overall emergency response strategy [8] This capability is particularly critical in urban environments, where each second is vital, and effective coordination can preserve lives and mitigate property damage.

Beyond merely improving detection accuracy, integrating IoT devices within fire monitoring systems revolutionizes emergency response strategies. The seamless communication between these devices and emergency response systems significantly reduces RTs during fire incidents. By transmitting real-time alerts to firefighters, urban management authorities, and residents, IoT-enabled systems facilitate quicker interventions and optimize resource allocation, thereby enhancing overall safety.

IoT sensors' ability to continuously monitor environmental conditions is one of their most significant advantages. For instance, when a sensor detects an abnormal increase in temperature or identifies smoke particles, it can immediately notify nearby fire stations and initiate automated emergency protocols. This swift action can include alerting fire crews to mobilize, directing them to the specific incident location, and even providing critical data about the nature of the threat. This proactive approach minimizes the time from detection to action, a crucial factor in fire emergencies where every second counts.

The importance of rapid response cannot be overstated in urban environments, where dense populations and complex infrastructures pose unique challenges. Fire incidents in such areas require quick detection and effective coordination among multiple agencies. IoT systems can facilitate this by integrating with other urban management tools, such as traffic management systems, to ensure that fire trucks can navigate to the scene without delays caused by congested roads. By relaying real-time data about traffic conditions and available routes, these systems enhance the efficiency of emergency responses.

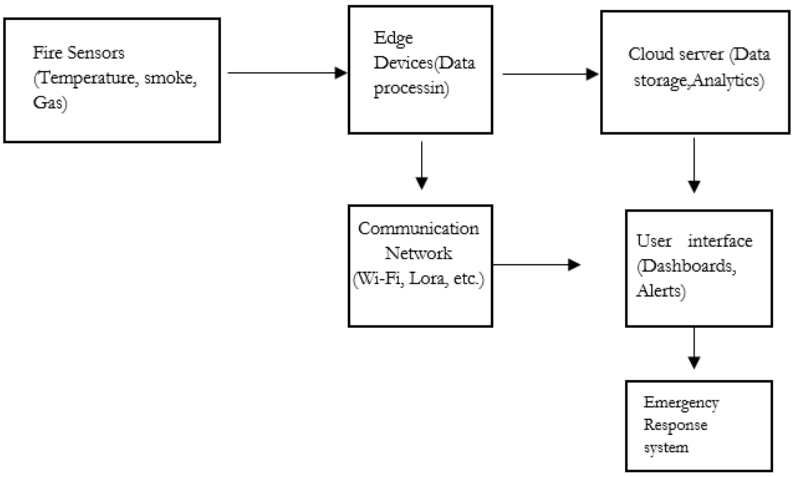

Fig. 1. System architecture design for IoT-based fire monitoring system.

Moreover, integrating data from multiple IoT devices enhances situational awareness during emergencies. By consolidating information from diverse sources, emergency responders can comprehensively understand the incident's context, including environmental sensors, surveillance cameras, and building management systems. This data-driven methodology facilitates informed decision-making, empowering responders to evaluate the fire's intensity, trajectory, and potential spread before they arrive at the scene [9]. Such advanced analytics are vital for formulating effective containment strategies and optimizing resource deployment during fire incidents. Notwithstanding these advancements, several challenges remain in developing and implementing IoT-enabled fire monitoring systems. Challenges such as ensuring system scalability, preserving data integrity, and minimizing false alarms must be addressed to guarantee the reliability and efficacy of these solutions [10]. For instance, as the number of connected devices proliferates, managing the volume of generated data becomes increasingly intricate. Effective strategies must be devised to filter and prioritize data, ensuring that emergency services can concentrate on actionable insights rather than being inundated with excessive information. This paper proposes a novel IoT-based fire monitoring and response system tailored to urban environments. The objectives of the system are as follows:

Early detection: To implement a network of smart sensors that continuously monitor environmental conditions, enabling the early detection of fire incidents through real-time data analysis.

Enhanced accuracy: To employ deep learning algorithms that improve the accuracy of fire classification, significantly reducing false alarms and ensuring reliable threat assessment.

Rapid response coordination: To facilitate seamless communication between IoT devices and emergency response teams, ensuring rapid dissemination of alerts and coordinated actions during fire emergencies.

Data fusion: To integrate data from multiple IoT sources, including temperature, smoke, and gas sensors, as well as video surveillance, to enhance situational awareness and provide comprehensive insights into fire incidents.

Resource optimization: To develop algorithms that assist in optimizing resource allocation and deployment for firefighting teams based on real-time incident analysis and predictions.

Scalability and interoperability: To ensure the system can scale effectively with the growing number of IoT devices in urban environments and maintain interoperability with existing emergency response frameworks.

Community engagement: To create a platform for citizen involvement, allowing residents to receive alerts and contribute information during fire emergencies, enhancing community resilience.

Performance evaluation: To establish metrics for evaluating system performance, including RTs, detection accuracy, and overall effectiveness in mitigating fire risks in urban areas.

Continuous learning: To implement mechanisms for continuous system improvement through machine learning, enabling it to adapt and evolve based on new data and changing urban conditions.

Awareness and training: To provide educational resources and training for emergency responders and the public, promoting awareness of the system's capabilities and best practices for fire safety.

2 | Workflow Diagram

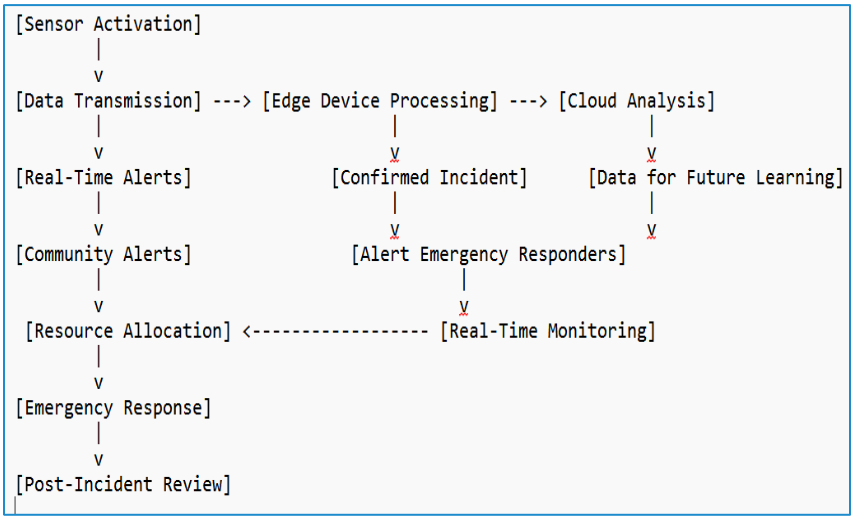

Fig. 2. System workflow diagram for IoT-based fire monitoring system.

This workflow diagram effectively communicates the comprehensive fire detection and response process within an IoT framework, emphasizing the system's efficiency and integration capabilities. Including this figure in your paper will visually complement your discussion of IoT's advantages in enhancing urban fire safety.

Considering these factors, the present paper investigates a comprehensive IoT-enabled framework for real-time fire monitoring and response within urban areas. By underscoring the significance of deep learning and data fusion, this study aims to offer a holistic approach that addresses existing challenges while enhancing the safety and resilience of urban environments. Through the proposed framework, we aspire to contribute to the evolution of smarter, safer cities that are equipped to respond effectively to fire hazards.

In the dynamic field of fire safety management, evaluating the effectiveness and efficiency of conventional fire detection systems about contemporary IoT-based solutions is imperative. To understand the advancements offered by IoT technologies in fire safety, we present a comparative analysis of traditional fire detection systems and IoT-based fire monitoring solutions. This comparison focuses on several critical parameters, allowing us to evaluate both approaches' effectiveness, efficiency, and adaptability in urban environments. The following table summarizes each system's key differences and advantages, providing insights into how IoT technologies can enhance fire detection and response strategies.

Table 1. Comparison of traditional fire detection systems and IoT-based fire monitoring systems.

	Parameters	Traditional Based	Iot-Based
1	Direction Speed	Slow	Fast
2	Scalability	Limited	High
3	Cost	High	Long term low
4	Maintenance	High	Low

Parameters considered for comparison include:

Detection speed: Measures how quickly each system can identify a fire event, which is critical for minimizing damage and ensuring safety.

Scalability: Assesses how easily each system can expand to accommodate more sensors or integrate with additional technologies as urban environments grow

Cost: looks at the overall implementation and maintenance costs associated with traditional systems versus IoT-based solutions.

2.1 | Detection Speed

Refers to the time taken from fire detection by sensors to alerting the response team.

Use: Critical for assessing the effectiveness of the fire monitoring system

$$[\ DS = t_{alert} - t_{detection}\ ]. \tag{1}$$

Where t-alert is when the alert is sent, and t-detection is when the fire is detected.

2.2 | False Alarm Rate

The percentage of false alarms generated by the system. Effectively managing false alarms is vital for ensuring the reliability and credibility of fire detection systems. Reducing false alarms enhances resource efficiency, maintains public trust, and improves emergency safety outcomes.

Use: Important for evaluating system reliability and minimizing unnecessary resource allocation.

$$[\ FAR= (N_{false\ alarms} / N_{total\ alarms}) \times 100\ ]. \tag{2}$$

N-false alarms are the number of false alarms, and N-total alarms are the total number of triggered alarms.

2.3 | Response Time

It refers to emergency responders arriving at the fire location after being alerted.

Use: Indicates the efficiency of the response system.

$$RT= [\ t_{arrival} - t_{alert}\ ], \tag{3}$$

Where t-arrival is the time of arrival at the incident site.

2.4 | Scalability Factor

It measures how well the system can accommodate increasing sensors/devices. The Scalability Factor (SFA) is essential for ensuring fire detection systems can grow and adapt to changing needs while maintaining performance and cost-effectiveness. A scalable system enhances overall safety, flexibility, and the ability to respond to emerging challenges in urban environments.

Use: Assesses the system's ability to expand without significant performance degradation.

$$SF= P_{max} / P_{current}, \tag{4}$$

where p-max is the maximum number of devices the system can handle, and Pcurrent is the current number of devices.

2.5 | Cost Efficiency

It measures the system's cost-effectiveness based on implementation and operational costs versus performance.

Use: To evaluate the financial feasibility of adopting IoT solutions.

[CE=Performance Index / Total Cost]. **(5)**

The Performance Index might be a composite score of detection accuracy, RT, etc.

3 | Probable Equations for Machine Learning Models

3.1 | Classification Accuracy

It measures how often the classifier is correct. Accuracy in fire detection systems is vital for ensuring safety, building trust, and optimizing emergency response efforts. It plays a fundamental role in the overall effectiveness and reliability of IoT-based fire monitoring solutions.

[CS=TP+TN / TP+TN + FP+FN]. **(6)**

Where TP is True Positives, TN is True Negatives, FP = False Positives, FN = False Negatives.

3.2 | Precision (P)

The ratio of correctly predicted positive observations to the total predicted positives. Precision is a crucial metric in fire detection systems, particularly in IoT-based solutions, where the accuracy of identifying actual fire events directly impacts response effectiveness and resource.

[P=TP/TP+FP]. **(7)**

Author Contribution

Conceptualization: Shrivastava developed the overall research idea and framework, ensuring alignment with the project's objectives.

Methodology: Shrivastava and Abhinav Gogoi designed the research methods, outlining how the data would be collected and analyzed.

Software: Sai Chaitanya developed and implemented data collection and analysis tools, ensuring functionality and user-friendliness.

Validation: Sharad Shahi, Abhinav Gogoi, and Aadhya Shrivastava collaborated to verify the accuracy and reliability of the risearch findings, conducting various tests to ensure robust results.

Funding

This section acknowledges the various forms of support that contributed to the success of this research but are not explicitly mentioned in the Author Contribution or Funding sections.

We want to thank the technical staff at [KIIT, School of Computer Science and Communication Engineering], who assisted in setting up the IoT sensor networks and ensuring their optimal functioning throughout the study. Their expertise in troubleshooting and maintaining the devices greatly facilitated our data collection efforts.

Additionally, we appreciate the support from [IoT Laboratory, KIIT], which generously donated the sensors and equipment used in our experiments. Their contribution enhanced the quality of our research and allowed us to conduct a more comprehensive analysis of fire detection capabilities in urban environments.

Lastly, we acknowledge the administrative support from [Department Of Computer Science], which helped streamline the logistics of our project, from coordinating meetings to managing documentation. Their efforts were crucial in ensuring that the research progressed smoothly and efficiently.

This collaborative effort underscores the importance of teamwork and resource sharing in advancing research and improving fire safety outcomes in urban settings.

Data Availability

We empower authors to make their research publicly available to increase transparency and reproducibility in scientific research.

Conflicts of Interest

The authors hereby declare that there are no conflicts of interest. There are no personal circumstances or interests that might be perceived as exerting an inappropriate influence on the presentation or interpretation of the research findings reported herein.

Additionally, we disclose that the funding sources were not involved in the study's design, data collection, analysis, interpretation, manuscript composition, or decision-making process regarding the publication of the results. All facets of the research were conducted autonomously, safeguarding the integrity and objectivity of the findings presented in this document.

References

[1] Ivanov, M. L., & Chow, W. K. (2023). Fire safety in modern indoor and built environment. *Indoor and Built Environment*, *32*(1), 3-8. https://doi.org/10.1177/1420326X2211347

[2] Khan, F., Xu, Z., Sun, J., Khan, F. M., Ahmed, A., & Zhao, Y. (2022). Recent advances in sensors for fire detection. *Sensors*, *22*(9), 3310. https://doi.org/10.3390/s22093310

[3] Vasconcelos, R. N., Franca Rocha, W. J. S., Costa, D. P., Duverger, S. G., Santana, M. M. M. de, Cambui, E. C. B., … & Cordeiro, C. L. (2024). Fire detection with deep learning: A comprehensive review. *Land*, *13*(10), 1696. https://doi.org/10.3390/land13101696

[4] Cheng, G., Chen, X., Wang, C., Li, X., Xian, B., & Yu, H. (2024). Visual fire detection using deep learning: A survey. *Neurocomputing*, *596*, 127975. https://doi.org/10.1016/j.neucom.2024.127975

[5] Morchid, A., Oughannou, Z., Alami, R. El, Qjidaa, H., Jamil, M. O., & Khalid, H. M. (2024). Integrated internet of things (IoT) solutions for early fire detection in smart agriculture. *Results in engineering*, *24*, 103392. https://doi.org/10.1016/j.rineng.2024.103392

[6] Mohapatra, H., & Rath, A. K. (2021). An IoT based efficient multi-objective real-time smart parking system. *International journal of sensor networks*, *37*(4), 219–232. https://doi.org/10.1504/IJSNET.2021.119483

[7] Intorelli, A., Braig, D., & Moquin, R. (2009). Real-time data fusion and visualization in support of emergency response operations. *2009 IEEE conference on technologies for homeland security* (pp. 417–424). IEEE. https://doi.org/10.1109/THS.2009.5168067

[8] Avgeris, M., Spatharakis, D., Dechouniotis, D., Kalatzis, N., Roussaki, I., & Papavassiliou, S. (2019). Where there is fire there is smoke: A scalable edge computing framework for early fire detection. *Sensors*, *19*(3), 639. https://doi.org/10.3390/s19030639

[9] Patel, H., Patel, S., Shah, M., & Sharma, L. (2018). Real time multi sensor technique for false alarm reduction using IoT. *Journal of analysis and computation (JAC)*, *11*(1), 1-20. https://doi.org/10.57046/RFPT1725

[10] Mohapatra, H., Mohanta, B. K., Nikoo, M. R., Daneshmand, M., & Gandomi, A. H. (2022). MCDM-based routing for IoT-enabled smart water distribution network. *IEEE internet of things journal*, *10*(5), 4271–4280. https://doi.org/10.1109/JIOT.2022.3216402

Appendix A

Appendix A: Architectural design *Fig. 1*.

Fig. 1 illustrates the architectural design of the IoT-based fire detection system. This figure depicts the overall framework, including various components such as IoT sensors, communication networks, emergency response systems, and data management platforms. The design emphasizes the integration of real-time data collection with automated alert mechanisms that facilitate swift emergency responses.

Fig. 1: Architectural design of the IoT-based fire detection system.

Appendix B

Workflow Diagram *Fig. 2*

Fig. + presents a workflow diagram to further elucidate the operational processes of the fire detection system. This diagram outlines the sequential steps taken from the initial detection of a fire by IoT sensors to the communication of alerts to emergency services and residents. It details the automated protocols triggered upon detection, showcasing how data flows through the system and the interactions among various stakeholders involved in the emergency response.

Fig. 2: Workflow diagram of the fire detection and response process

Appendix C

Additional data

This section contains supplementary data and details regarding the experiments conducted as part of this research. It includes expanded descriptions of the methodologies employed, specific parameters used in the analysis, and any relevant statistical analyses not included in the main text.

For example, additional insights are presented into the performance metrics of the IoT sensors used, such as sensitivity, specificity, and RTs. These metrics provide a more comprehensive understanding of the system's effectiveness in real-world applications.

Appendix D

Mathematical proofs *Eq. (1)-(6)*

While the main manuscript's primary focus is on practical applications, this section includes relevant mathematical proofs that support the algorithms used for data analysis and interpretation. These proofs detail the underlying principles governing sensor accuracy and the decision-making processes employed in the system's operational framework.