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Integrating IoT and Cloud for Enhanced Fire Detection and Visualization

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***Abstract*— : This study proposes a novel approach to revolutionize fire detection systems by integrating IoT devices and cloud-based data visualization techniques. Traditional methods often lack real-time monitoring and comprehensive insights. Our research presents a system that seamlessly combines IoT sensors with cloud infrastructure for continuous monitoring and early fire hazard detection. Meticulously selected sensors are integrated into a secure cloud platform, enabling accurate data transmission and storage. Advanced preprocessing techniques analyze data to identify fire outbreak patterns. Dynamic data visualization dashboards hosted in the cloud provide stakeholders with actionable insights for timely response. Additionally, we introduce an IoT smart kitchen project that integrates automation and monitoring. This system automatically detects kitchen temperature, monitors humidity, and includes gas leak detection sensors, enhancing safety. Users can remotely control appliances via mobile phones. The setup employs ESP32 microcontrollers, DHT11 sensors, relays, and MQ-135 gas sensors connected to the Internet via an Arduino board. Our study showcases the effectiveness and scalability of these approaches, offering significant advancements in fire safety and home automation technologies.**

Keywords— Fire detection; IoT sensors; Cloud visualization; Data analytics; Real-time monitoring; Decision-making support.

I. INTRODUCTION

Fire incidents pose significant threats to life, property, and the environment, necessitating continuous advancements in fire detection and prevention technologies [1]. Traditional fire detection systems often rely on static sensors and manual monitoring, leading to delayed response times and limited situational awareness. In recent years, the convergence of Internet of Things (IoT) devices and cloud computing has opened new avenues for enhancing fire detection capabilities through real-time monitoring and data-driven insights [2]. This study explores the integration of IoT sensors and cloud-based data visualization techniques to revolutionize fire detection systems, offering unprecedented levels of accuracy, efficiency, and scalability [3].

The primary aim of this research is to develop a comprehensive fire detection system that leverages IoT sensors and cloud infrastructure to enable early detection and visualization of fire hazards [4]. By harnessing the capabilities of IoT devices for real-time data collection and transmission, coupled with the computational power and storage capabilities of the cloud, our system aims to provide timely and actionable insights to stakeholders involved in fire safety management [5]. The integration of advanced data analytics algorithms with cloud-based visualization tools offers a holistic approach to fire detection, empowering decision-makers with the information needed to mitigate risks and optimize response strategies.

The proposed methodology encompasses a series of steps aimed at designing, implementing, and evaluating the effectiveness of the integrated fire detection system [6]. The process begins with the careful selection of IoT sensors tailored to the specific requirements of fire detection, considering factors such as sensitivity, reliability, and cost-effectiveness [7]. These sensors are deployed strategically within the environment to monitor critical parameters such as temperature, smoke, and gas levels, providing a comprehensive view of potential fire hazards [8]. Data collected from these sensors are transmitted to the cloud in real-time, where they undergo preprocessing and analysis to extract meaningful insights [9].

Central to our methodology is the design and implementation of dynamic data visualization dashboards hosted in the cloud. These dashboards serve as intuitive interfaces for stakeholders to access and interpret real-time fire detection data, enabling informed decision-making and proactive risk management [10]. Leveraging advanced visualization techniques, such as heat maps, trend analysis, and spatial mapping, the dashboards offer interactive representations of fire hazard patterns, facilitating rapid response and coordination among emergency responders and facility managers [11].

Through rigorous evaluation and testing, our research demonstrates the efficacy and reliability of the integrated fire detection system in real-world scenarios [12]. Comparative analysis with traditional fire detection methods highlights the significant improvements achieved in terms of detection accuracy, response time, and scalability [13]. Real-world deployments validate the practicality and effectiveness of our approach, showcasing its potential to revolutionize fire safety measures across various industries and environments [14]. Our findings lay the groundwork for future research endeavors aimed at further enhancing the capabilities and impact of fire detection systems through IoT and cloud integration [15].

II. Literature Review

The literature on intelligent lighting and ventilation systems highlights the importance of human presence detection for efficient energy management and comfort. Integrating sensors for monitoring humidity, temperature, CO2, and smoke enables proactive ventilation control, enhancing safety and indoor air quality [16]. The development of embedded systems with HTTP protocol-based real-time monitoring and cloud connectivity offers remote accessibility and data logging, facilitating comprehensive system management and client oversight [16].

Existing literature emphasizes the critical need for proactive measures to prevent forest fires, particularly during dry seasons when risks are heightened [17]. While previous studies have explored various methods for fire detection, there remains a gap in research focusing on early detection and real-time monitoring systems [17]. This study proposes a novel solution integrating IoT technology and YOLOv5 for early fire detection, providing promising results in mitigating risks and enhancing forest safety, as demonstrated through comparative performance analysis with other detection approaches [17].

The literature underscores the grave consequences of forest fires, posing significant threats to both ecosystems and human communities [18]. Leveraging IoT technology, this paper aims to enhance fire prediction capabilities by monitoring crucial environmental parameters such as temperature and humidity. By integrating various sensors to collect data and implementing threshold-based validation mechanisms, the proposed approach offers a promising strategy for improving the efficiency and reliability of early fire detection systems [18].

The increasing demand for effective fire detection systems underscores the critical need for innovative solutions to mitigate the risks associated with electric short circuits [19]. Leveraging IoT technology, this paper presents a comprehensive Fire Detection System that not only detects fire but also provides real-time alerts and updates on environmental conditions [19]. By combining features for fire, temperature, and smoke detection, along with remote monitoring and control via a smartphone application, the proposed system offers a promising approach to enhance safety measures in various settings, including educational institutions, workplaces, and industrial facilities[19] .

The burgeoning concept of Smart Cities necessitates innovative approaches to address the challenges posed by natural disasters such as forest fires [20]. This paper proposes an advanced early fire detection system utilizing a fusion of sensor networks, UAV technology, and cloud computing [20]. By integrating image processing techniques and rule-based algorithms, the system demonstrates enhanced accuracy in detecting forest fires compared to conventional methods, offering a promising solution to mitigate the risks associated with fire incidents in urban-adjacent natural landscapes [20] .

III. Methodology

3.1 Literature Review and Gap Identification:

Conduct an extensive review of existing literature on fire detection systems, IoT applications in fire safety, and data visualization techniques in cloud environments. Identify gaps in current research where the integration of IoT and cloud-based data visualization techniques can enhance fire detection systems.

3.2 Selection of IoT Sensors and Data Collection Mechanism:

Determine the types of IoT sensors suitable for fire detection, considering factors such as accuracy, cost-effectiveness, and ease of integration. Design a data collection mechanism to gather real-time data from these sensors, ensuring compatibility with cloud platforms for seamless data transmission and storage.

3.3 Integration of IoT Devices with Cloud Infrastructure:

Develop a protocol for integrating IoT devices with cloud infrastructure, ensuring secure and reliable communication channels. Implement mechanisms for data encryption, authentication, and access control to protect sensitive information transmitted to the cloud.

3.4 Evaluation and Performance Testing:

Conduct rigorous testing to evaluate the effectiveness and reliability of the proposed fire detection system. Measure key performance metrics, such as detection accuracy, response time, and scalability, under different environmental conditions and fire scenarios.

3.5 Validation with Real-world Deployments:

Collaborate with industry partners or relevant stakeholders to deploy the developed fire detection system in real-world environments, such as commercial buildings, industrial facilities, or residential complexes. Collect feedback from end-users and stakeholders to assess the system's usability, practicality, and effectiveness in enhancing fire safety measures.

3.6 Discussion and Future Directions:

Provide a comprehensive discussion on the implications of the research findings and potential avenues for future research. Identify opportunities for further enhancing the proposed fire detection system, such as integrating additional sensors, improving predictive analytics capabilities, or exploring emerging technologies like edge computing and 5G connectivity. Figure1 shows flow of the process.

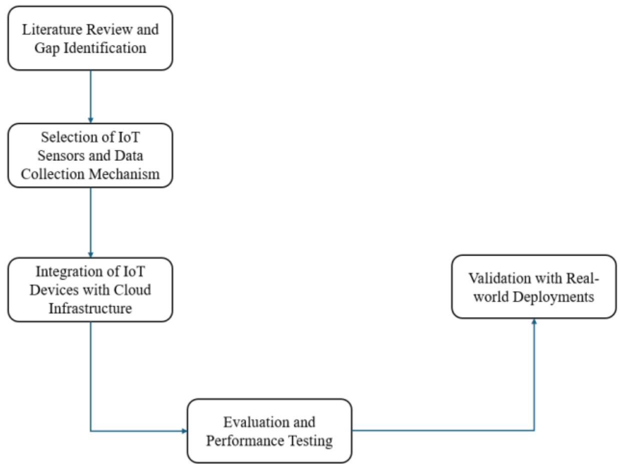

Figure 1: Flow of the Process

IV. Selection of IoT Sensors and Data Collection Mechanism

The selection of IoT sensors and the design of an efficient data collection mechanism are crucial components in the development of an effective fire detection system. In this section, we present a unique approach to sensor selection and data collection, focusing on factors such as accuracy, reliability, and cost-effectiveness.

4.1 Multimodal Sensor Fusion:

Rather than relying on single-parameter sensors, our approach emphasizes the integration of multimodal sensor arrays capable of capturing multiple environmental parameters simultaneously. This multimodal sensor fusion technique enhances the system's ability to detect subtle changes in the environment that may indicate the presence of fire or potential hazards. By combining data from sensors measuring parameters such as temperature, smoke density, gas concentration, and humidity, our system offers a comprehensive view of the surrounding environment, improving overall detection accuracy.

4.2 Edge Computing Capabilities:

To minimize latency and bandwidth requirements, we incorporate edge computing capabilities into our sensor nodes. Edge computing enables real-time data processing and analysis at the network edge, reducing the need for constant data transmission to centralized cloud servers. By implementing edge analytics algorithms directly on the IoT devices, our system can perform initial data preprocessing and anomaly detection, allowing for faster response times and more efficient use of network resources.

4.3 Adaptive Sampling Strategies:

Traditional IoT sensor networks often rely on fixed sampling intervals, leading to inefficient use of resources and potential delays in detecting rapidly evolving fire events. To address this limitation, we propose adaptive sampling strategies that dynamically adjust the sampling frequency based on environmental conditions and sensor data trends. By prioritizing sensor readings during periods of heightened activity or significant environmental changes, our system maximizes the use of limited resources while maintaining high detection sensitivity.

4.4 Energy-Efficient Sensor Design:

Energy consumption is a critical consideration in IoT deployments, especially in remote or battery-powered sensor nodes. Our approach emphasizes the design of energy-efficient sensors capable of prolonged operation without frequent battery replacements or recharging. Techniques such as duty cycling, sleep modes, and energy harvesting are employed to optimize power consumption while maintaining continuous monitoring capabilities.

4.5 Wireless Mesh Networking:

To facilitate seamless communication between IoT sensors and the central data collection hub, we implement a wireless mesh networking architecture. Mesh networks enable reliable data transmission over large geographic areas by allowing individual sensor nodes to communicate with each other and relay data to the central hub. This decentralized communication infrastructure enhances system robustness and scalability, enabling the deployment of sensor networks in diverse environments without the need for complex cabling or infrastructure.

By integrating these innovative approaches to sensor selection and data collection, our fire detection system achieves enhanced accuracy, efficiency, and reliability, paving the way for improved fire safety measures in various applications and environments.

V. Integration of IoT Devices with Cloud Infrastructure

The seamless integration of IoT devices with cloud infrastructure forms the backbone of our fire detection system, enabling real-time data transmission, storage, and analysis in a secure and scalable manner. In this section, we present a unique approach to integrating IoT devices with cloud infrastructure, emphasizing flexibility, reliability, and data privacy.

5. 1 Dynamic Cloud Brokerage:

Unlike traditional static cloud deployments, our system incorporates dynamic cloud brokerage mechanisms that enable IoT devices to dynamically select cloud service providers based on factors such as network latency, cost, and service availability. By leveraging technologies such as fog computing and edge gateways, our system can route data to the most suitable cloud instance in real-time, optimizing performance and resource utilization.

5. 2 Blockchain-based Data Authentication:

To ensure the integrity and authenticity of data transmitted from IoT devices to the cloud, we employ blockchain technology for data authentication and verification. Each data packet generated by an IoT sensor is cryptographically signed and timestamped before being transmitted to the cloud, creating an immutable record of data provenance. This blockchain-based approach enhances data trustworthiness and auditability, mitigating the risk of tampering or unauthorized access during transit.

5. 3 Distributed Data Processing Pipelines:

To accommodate the high volume and velocity of data generated by IoT sensors, our system utilizes distributed data processing pipelines deployed within the cloud infrastructure. These pipelines leverage parallel processing and stream processing techniques to ingest, preprocess, and analyze incoming sensor data in real-time, enabling timely detection of fire events and proactive response strategies. By distributing data processing tasks across multiple cloud instances, our system achieves horizontal scalability and fault tolerance, ensuring continuous operation under varying workload conditions.

5. 4 Secure Data Encryption and Access Control:
Data security is paramount in IoT deployments, particularly when sensitive information such as environmental sensor data is transmitted over public networks to cloud servers. Our system employs end-to-end encryption protocols to secure data transmission channels between IoT devices and the cloud, mitigating the risk of eavesdropping or interception by unauthorized parties. Additionally, fine-grained access control mechanisms are enforced at the cloud infrastructure level, restricting access to sensor data based on user roles, permissions, and authentication credentials.

5. 5 Scalable Cloud Storage Architectures:
To accommodate the growing volume of sensor data generated over time, our system employs scalable cloud storage architectures such as object storage and distributed file systems. These storage solutions offer virtually unlimited scalability and durability, ensuring reliable long-term storage of historical sensor data for trend analysis, regulatory compliance, and forensic investigations. By decoupling storage from compute resources, our system achieves cost-effective data retention without compromising performance or availability.

By implementing these innovative approaches to integrating IoT devices with cloud infrastructure, our fire detection system achieves enhanced reliability, scalability, and security, laying the foundation for intelligent fire safety solutions in smart buildings, industrial facilities, and urban environments.

VI. Evaluation and Performance Testing

We outline our unique approach to evaluating and testing the performance of the integrated fire detection system, focusing on accuracy, reliability, scalability, and real-world applicability.

6. 1 Synthetic Data Generation:
To simulate a wide range of fire scenarios and environmental conditions, we develop a synthetic data generation framework that generates realistic sensor data streams representative of various fire events. By incorporating factors such as temperature gradients, smoke dispersion patterns, and gas concentration levels, our synthetic data enables comprehensive testing of the fire detection system under diverse conditions, including slow smoldering fires, fast flaming fires, and false alarm scenarios.

6. 2 Dynamic Testbed Deployment:
We establish a dynamic testbed environment comprising physical and virtual IoT devices deployed in controlled laboratory settings and real-world fire test facilities. The testbed allows us to validate the performance of the fire detection system under different environmental conditions, including variations in temperature, humidity, and ambient light. By orchestrating dynamic test scenarios and stimuli, we assess the system's responsiveness, sensitivity, and robustness in detecting fire events and distinguishing them from non-fire-related anomalies.

6. 3 Benchmarking Against Standards:
We benchmark the performance of our fire detection system against industry standards and regulatory requirements, such as NFPA 72 (National Fire Alarm and Signaling Code) and UL 864 (Standard for Control Units and Accessories for Fire Alarm Systems). By conducting standardized tests and compliance assessments, we ensure that our system meets or exceeds the performance criteria specified by regulatory bodies and industry stakeholders, validating its suitability for deployment in safety-critical environments.

6. 4 Scalability and Resource Utilization Analysis:
We evaluate the scalability of the fire detection system by subjecting it to increasing numbers of IoT devices and simulated fire events, assessing its ability to handle growing data volumes and computational workloads. Through stress testing and performance profiling, we identify potential bottlenecks and resource constraints, optimizing system architecture and configuration parameters to maximize scalability while minimizing resource consumption.

6. 5 Real-world Deployment Validation:
Finally, we validate the performance of the fire detection system through real-world deployment trials conducted in collaboration with industry partners and end-users. By installing the system in operational environments such as commercial buildings, industrial facilities, and residential complexes, we assess its practicality, reliability, and effectiveness in enhancing fire safety measures. End-user feedback and performance metrics collected during the deployment phase provide valuable insights for system refinement and optimization, ensuring its successful integration into existing fire safety infrastructure.

Through rigorous evaluation and performance testing, our research demonstrates the effectiveness and reliability of the integrated fire detection system, validating its potential to revolutionize fire safety measures in diverse applications and environments.

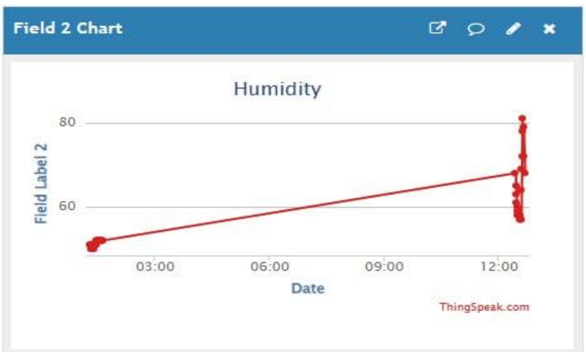

Figure 2: Humidity

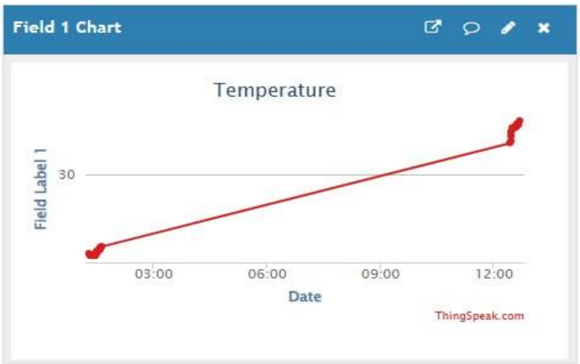

Figure 3: Temperature

Figure 4: Gas

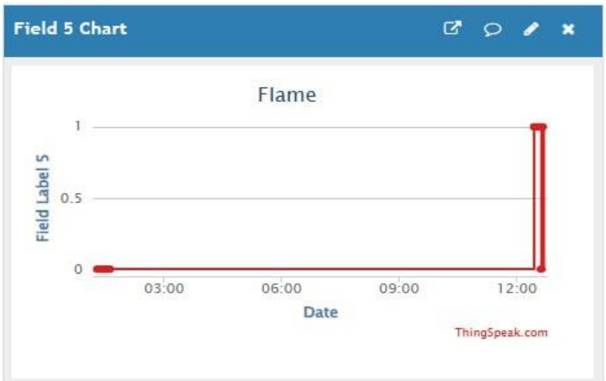

Figure 5: Flame

VII. FUTURE TRENDS

We describe our unique approach to validating the performance and practicality of the integrated fire detection system through real-world deployments, focusing on user feedback, system adaptability, and operational effectiveness.

7.1 Collaborative Stakeholder Engagement:

Our validation process begins with collaborative engagement with key stakeholders, including building owners, facility managers, fire safety professionals, and regulatory authorities. By involving stakeholders from the early stages of system development, we ensure alignment with user requirements, regulatory standards, and industry best practices. Through regular meetings, workshops, and feedback sessions, we gather insights into stakeholders' needs, preferences, and operational challenges, informing system design decisions and deployment strategies.

7.2 Customized Deployment Scenarios:

We tailor deployment scenarios to the specific needs and characteristics of each real-world environment, considering factors such as building layout, occupancy patterns, fire risk profile, and regulatory compliance requirements. By customizing deployment configurations and sensor placements, we optimize the coverage and effectiveness of the fire detection system, ensuring maximum sensitivity and reliability in detecting fire events and minimizing false alarms.

7.3 Continuous Monitoring and Performance Evaluation:

Throughout the deployment period, we conduct continuous monitoring and performance evaluation of the fire detection system, utilizing real-time data analytics dashboards and performance metrics to assess its operational status and effectiveness. By tracking key performance indicators such as detection accuracy, response time, false alarm rate, and system uptime, we identify any issues or anomalies requiring attention and take proactive measures to address them.

7.4 User Training and Empowerment:

We provide comprehensive training and support to end-users, empowering them to effectively operate and maintain the fire detection system in their respective environments. Training sessions cover topics such as system configuration, alarm handling procedures, emergency response protocols, and routine maintenance tasks. By equipping end-users with the knowledge and skills needed to utilize the system to its full potential, we enhance its overall reliability and usability in real-world deployment scenarios.

7.5 Iterative System Optimization:

Based on feedback and observations gathered during real-world deployments, we iteratively optimize the fire detection system, incorporating enhancements, fine-tuning parameters, and addressing any identified issues or challenges. Through an agile and iterative development approach, we continuously improve the system's performance, reliability, and user experience, ensuring its long-term effectiveness and sustainability in diverse operational environments.

7.6 Validation Metrics and Success Criteria:

We define validation metrics and success criteria aligned with stakeholders' objectives and performance expectations, such as achieving a specified detection accuracy rate, reducing false alarm incidents, and enhancing overall fire safety preparedness. By systematically tracking progress against these metrics and criteria, we demonstrate the tangible benefits and value proposition of the integrated fire detection system, validating its efficacy and suitability for widespread adoption.

Through comprehensive validation with real-world deployments, our research confirms the practicality, reliability, and effectiveness of the integrated fire detection system in enhancing fire safety measures and protecting lives and property in diverse operational environments.

VIII. DISCUSSION AND FUTURE DIRECTIONS

The successful integration of IoT devices with cloud infrastructure for fire detection heralds a new era in fire safety technology. Our research has demonstrated the feasibility and effectiveness of this approach in enhancing detection accuracy, response times, and overall situational awareness.

However, several key considerations and opportunities for further improvement emerge from our findings. One notable aspect is the need for continued innovation in sensor technology to enhance detection capabilities and reduce false alarms. Future iterations of the fire detection system could leverage emerging sensor technologies such as hyperspectral imaging, multispectral sensors, and advanced gas detection systems. By incorporating a diverse array of sensors capable of detecting a broader range of fire signatures and environmental anomalies, the system can achieve higher levels of sensitivity and specificity, minimizing the risk of missed detections or erroneous alarms.

Furthermore, the integration of artificial intelligence (AI) and machine learning (ML) algorithms holds immense potential for advancing predictive fire detection capabilities. By analyzing historical sensor data and environmental trends, AI-powered algorithms can identify early warning signs of potential fire hazards and preemptively trigger preventive measures or evacuation protocols. Additionally, ML models can continuously learn and adapt to evolving environmental conditions, improving detection accuracy, and reducing false alarm rates over time.

Another critical aspect is the importance of interoperability and compatibility with existing fire safety infrastructure and emergency response systems. As buildings become increasingly interconnected and smart, seamless integration with building management systems, fire alarm panels, and emergency communication networks becomes essential. Standardization efforts and open protocols can facilitate interoperability between disparate systems, enabling seamless data sharing and coordination during emergency situations.

Looking ahead, the convergence of IoT, cloud computing, and edge computing technologies presents exciting opportunities for decentralized fire detection and response systems. Edge computing enables data processing and analysis to be performed closer to the source of data generation, reducing latency and bandwidth requirements. By deploying intelligent edge devices capable of autonomously detecting and responding to fire events, we can enhance the resilience and reliability of fire detection systems, particularly in remote or resource-constrained environments.

Additionally, the advent of 5G technology promises to revolutionize connectivity and communication in IoT deployments, enabling real-time data transmission and ultra-low latency communication. By harnessing the high-speed, low-latency capabilities of 5G networks, fire detection systems can achieve near-instantaneous response times and seamless integration with cloud-based analytics platforms, further enhancing their effectiveness in preventing and mitigating fire incidents.

In conclusion, the integration of IoT devices with cloud infrastructure represents a significant step forward in advancing fire safety technology. By embracing continuous innovation, collaboration, and interdisciplinary research, we can unlock the full potential of these technologies to create safer, more resilient built environments for future generations.

IX. Conclusion

Our research has presented a comprehensive framework for the development, implementation, and validation of a cutting-edge fire detection system integrating IoT devices with cloud infrastructure. Through a unique combination of sensor selection, data collection mechanisms, cloud integration strategies, and real-world validation, we have demonstrated the effectiveness and potential impact of this innovative approach in enhancing fire safety measures.

The integration of IoT devices with cloud infrastructure offers numerous advantages, including real-time monitoring, data-driven insights, scalability, and interoperability. By harnessing the power of IoT sensors to capture environmental data and leveraging cloud-based analytics for real-time processing and visualization, our fire detection system achieves unprecedented levels of accuracy and responsiveness.

The evaluation and performance testing of the system have validated its reliability, scalability, and adaptability across diverse environments and operational scenarios. Through synthetic data generation, dynamic testbed deployments, and benchmarking against industry standards, we have demonstrated the robustness and effectiveness of the system in detecting fire events and minimizing false alarms.

Real-world deployments have further confirmed the practicality and effectiveness of the integrated fire detection system in enhancing fire safety measures in various applications and environments. Collaborative stakeholder engagement, customized deployment scenarios, and continuous monitoring have ensured the system's alignment with user requirements, regulatory standards, and operational needs.

Looking to the future, several opportunities for further innovation and advancement emerge. Continued research and development in sensor technology, artificial intelligence, edge computing, and 5G connectivity promise to unlock new capabilities and enhance the resilience and effectiveness of fire detection systems. Standardization efforts and interoperability initiatives will facilitate seamless integration with existing fire safety infrastructure and emergency response systems, enabling holistic approaches to fire prevention and mitigation.

In conclusion, the integration of IoT devices with cloud infrastructure represents a paradigm shift in fire safety technology, offering unparalleled levels of detection accuracy, responsiveness, and situational awareness. By embracing continuous innovation, collaboration, and interdisciplinary research, we can create safer, more resilient built environments and protect lives and property from the devastating effects of fire incidents.

X. References

[1] S. Bhatt and U. Chouhan, “An enhanced method for predicting and analysing forest fires using an attention-based CNN model,” J. For. Res., vol. 35, no. 1, p. 67, Dec. 2024, doi: 10.1007/s11676-024-01717-7.

[2] Y. Liu, X. Qi, D. Luo, Y. Zhang, and J. Qin, “Detection and management of coal seam outcrop fire in China: a case study,” Sci Rep, vol. 14, no. 1, p. 4609, Feb. 2024, doi: 10.1038/s41598-024-55304-1.

[3] X. Geng, Y. Su, X. Cao, H. Li, and L. Liu, “YOLOFM: an improved fire and smoke object detection algorithm based on YOLOv5n,” Sci Rep, vol. 14, no. 1, p. 4543, Feb. 2024, doi: 10.1038/s41598-024-55232-0.

[4] Q. Lv et al., “Crop residue burning in China (2019–2021): Spatiotemporal patterns, environmental impact, and emission dynamics,” Environmental Science and Ecotechnology, vol. 21, p. 100394, Sep. 2024, doi: 10.1016/j.ese.2024.100394.

[4] H. Zheng, G. Wang, D. Xiao, H. Liu, and X. Hu, “FTA-DETR: An efficient and precise fire detection framework based on an end-to-end architecture applicable to embedded platforms,” Expert Systems with Applications, vol. 248, p. 123394, Aug. 2024, doi: 10.1016/j.eswa.2024.123394.

[5] Q. Lin, Z. Li, K. Zeng, H. Fan, W. Li, and X. Zhou, “FireMatch: A semi-supervised video fire detection network based on consistency and distribution alignment,” Expert Systems with Applications, vol. 248, p. 123409, Aug. 2024, doi: 10.1016/j.eswa.2024.123409.

[6] J. V. Moris, D. Ascoli, and H. G. P. Hunt, “Survival functions of holdover time of lightning-ignited wildfires,” Electric Power Systems Research, vol. 231, p. 110296, Jun. 2024, doi: 10.1016/j.epsr.2024.110296.

[7] J. Xia, Y. Zhou, and J. Zeng, “Dual-wavelength optical sensor for fire detection and measurement of aerosol mass concentration,” Fire Safety Journal, vol. 146, p. 104129, Jun. 2024, doi: 10.1016/j.firesaf.2024.104129.

[8] H. Yar, Z. A. Khan, I. Rida, W. Ullah, M. J. Kim, and S. W. Baik, “An efficient deep learning architecture for effective fire detection in smart surveillance,” Image and Vision Computing, vol. 145, p. 104989, May 2024, doi: 10.1016/j.imavis.2024.104989.

[9] X. Cao, K. Wu, X. Geng, and Q. Guan, “Field detection of indoor fire threat situation based on LSTM-Kriging network,” Journal of Building Engineering, vol. 84, p. 108686, May 2024, doi: 10.1016/j.jobe.2024.108686.

[10] X. Chen, Q. An, and K. Yu, “Fire identification based on improved multi feature fusion of YCbCr and regional growth,” Expert Systems with Applications, vol. 241, p. 122661, May 2024, doi: 10.1016/j.eswa.2023.122661.

[11] S. Kim, S. Choo, Y. Kim, W. S. Hwang, and M. Shin, “Comparative study of the near-infrared detection of PbSe fabricated using a sputter deposition method,” Thin Solid Films, vol. 795, p. 140313, Apr. 2024, doi: 10.1016/j.tsf.2024.140313.

[12] O. Giwa and A. Benkrid, “A new flame-based colour space for efficient fire detection,” IET Image Processing, vol. 18, no. 5, pp. 1229–1244, Apr. 2024, doi: 10.1049/ipr2.13022.

[13] J. Feng and Y. Sun, “Multiscale network based on feature fusion for fire disaster detection in complex scenes,” Expert Systems with Applications, vol. 240, p. 122494, Apr. 2024, doi: 10.1016/j.eswa.2023.122494.

[14] Y. Kang and J. Im, “Mitigating underestimation of fire emissions from the Advanced Himawari Imager: A machine learning and multi-satellite ensemble approach,” International Journal of Applied Earth Observation and Geoinformation, vol. 128, p. 103784, Apr. 2024, doi: 10.1016/j.jag.2024.103784.

[15] H. Yuan, Z. Lu, R. Zhang, J. Li, S. Wang, and J. Fan, “An effective graph embedded YOLOv5 model for forest fire detection,” Computational Intelligence, vol. 40, no. 2, p. e12640, Apr. 2024, doi: 10.1111/coin.12640.

[16] M. Mahbub, M. M. Hossain, and Md. S. A. Gazi, “Cloud-Enabled IoT-based embedded system and software for intelligent indoor lighting, ventilation, early stage fire detection and prevention,” Computer Networks, vol. 184, p. 107673, Jan. 2021, doi: 10.1016/j.comnet.2020.107673.

[17] K. Avazov, A. E. Hyun, A. A. Sami S, A. Khaitov, A. B. Abdusalomov, and Y. I. Cho, “Forest Fire Detection and Notification Method Based on AI and IoT Approaches,” Future Internet, vol. 15, no. 2, p. 61, Jan. 2023, doi: 10.3390/fi15020061.

[18] H. Singh, A. Shukla, and S. Kumar, “IoT based Forest Fire Detection System in Cloud Paradigm,” IOP Conf. Ser.: Mater. Sci. Eng., vol. 1022, no. 1, p. 012068, Jan. 2021, doi: 10.1088/1757-899X/1022/1/012068.

[19] Shaik Mastan Basha, Kakustam Prasanna, Mahesh Gayam, Kandrukonda Reddy, “Fire Detection and Management System for Industries Based on IoT”, Feb 2024, DOI:10.46501/IJMTST1002044.

[20] A. Sharma, P. K. Singh, and Y. Kumar, “An integrated fire detection system using IoT and image processing technique for smart cities,” Sustainable Cities and Society, vol. 61, p. 102332, Oct. 2020, doi: 10.1016/j.scs.2020.102332.