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A Review on Fire and Smoke Detection With Intelligent Control for Enhanced Safety Using Machine Learning (ML) and Internet of Things (IoT)

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Abstract

In today's world, combating fire accidents in high-risk environments like industrial facilities and large structures is a significant challenge. Deploying firefighters to such locations is not only perilous but also endangers their lives. To address such types of critical issues, this review paper suggests cutting-edge technologies, specifically, Machine Learning (ML) and Internet of Things (IoT) sensors, to develop autonomous fire-extinguishing robots. This suggested approach aims to enhance early fire detection and firefighting capabilities, prioritizing safety in hazardous environments. The system involves creating an intelligent bot using ML and IoT technologies. Outfitted with an array of sensors, including ultrasonic, lidar, gas detectors, and smoke detectors, the bot collects crucial data related to fire incidents. With features like cameras and microcontrollers, the bot allows seamless remote control. The ML capabilities embedded in the system empower the bot to detect fire and transmit relevant information for swift decision-making. By relying on sensor data, the bot aims to optimize control measures, minimizing risks for firefighters. This pioneering approach ensures enhanced safety measures and marks a significant stride toward a safer and more efficient future in firefighting operations. Through the convergence of ML, especially Convolutional Neural Networks and IoT, this solution presents a transformative paradigm for fire management in hazardous scenarios, promising a safer and more efficient future. This paper provides a thorough review of fire and smoke detection features, advantages, and innovative contributions to fire safety challenges using artificial intelligence. Additionally, we identified a research gap, noting that previous literature has primarily focused on traditional methods or fully autonomous solutions, with little attention given to hybrid approaches. In response to this gap, our review specifically explores and suggests the hybrid solution that integrates both traditional and autonomous firefighting techniques.

Categories: AI applications, IoT Applications, Machine Learning (ML)
Keywords: fire detection and control, machine learning, convolutional neural networks, internet of things (iot), robotics

Introduction And Background

High-rise apartments, which represent the epitome of contemporary urban living, pose distinctive challenges when it comes to ensuring fire safety. Residing in the sky offers unparalleled vistas and conveniences, but it also introduces specific fire hazards. The presence of electrical systems, HVAC (heating, ventilation, and air conditioning) units, and densely populated living spaces can greatly facilitate the rapid spread of fire [1]. Moreover, balconies and communal areas may potentially serve as sources of ignition, thereby necessitating a comprehensive approach to fire safety. According to the National Crime Records Bureau, the number of fire accidents in India has reduced by over 40% between 2014 and 2018. However, the number of deaths per year is still above 10,000 (Figure *1*) [2].

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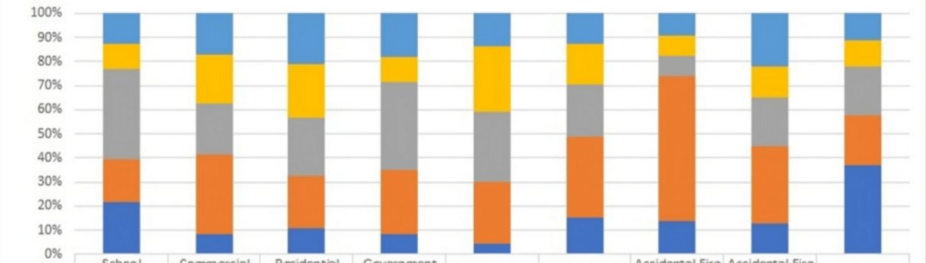

	School Buildings	Commercial Buildings	Residential Buildings	Government Buildings	Mines	Factories	Accidental Fire in Trains	Accidental Fire in Vehicles	Others
2018	7	367	7241	24	13	235	9	502	4701
2017	6	446	7660	13	26	311	8	286	4641
2016	21	463	8359	48	28	404	8	458	8772
2015	10	716	7493	35	25	622	58	719	8772
2014	12	179	3736	11	4	286	13	288	15848

FIGURE 1: Graph showing the location-wise percentage of fire incidents reported in India in 2014-2018

Technology plays a crucial role in improving fire safety in tall buildings. Real-time monitoring through smart fire detection systems equipped with sensors and artificial intelligence ensures early detection [3]. The development of fire-resistant materials and innovative evacuation plans is an ongoing process to address the unique challenges presented by vertical living. Advanced technologies, such as smart evacuation routes and automated emergency response systems, contribute to a more streamlined and secure evacuation process [4].

Traditional fire safety methods rely on sending firefighters into hazardous locations, which comes with inherent risks [5]. Firefighters often face danger in unpredictable situations, highlighting the need for alternative and technologically advanced approaches. Innovations like autonomous fire-extinguishing robots and artificial intelligence (AI)-driven systems aim to minimize risks and improve efficiency in firefighting operations [3,6].

However, firefighting robots provide a transformative solution that offers significant benefits (Figure *2*). These robots can navigate dangerous environments, reducing the need for humans to enter hazardous areas and minimizing the risk of injuries or fatalities [7]. With their 24/7 availability, they tirelessly operate and provide an immediate and continuous response to fire incidents. By accessing confined spaces and utilizing real-time data monitoring and AI integration, these robots enhance situational awareness and enable proactive firefighting strategies [7]. These autonomous machines contribute to quick response times, efficient resource allocation, and the ability to be operated remotely, demonstrating their effectiveness in dynamic and unpredictable firefighting scenarios [7,8]. While firefighting robots offer unmatched advantages, a comprehensive and effective emergency response can be achieved by combining both robotic and traditional firefighting methods in a synergistic approach.

This suggested approach is all about using advanced tools like microcontrollers and sensors to control fires from a safe distance. This helps us handle emergencies more effectively and swiftly, aiming for improved firefighting precision and efficiency. In this review paper, we present an approach designed to minimize the hazardous effects of fire by enabling early detection and prompt control measures, ultimately reducing potential losses. Our focus is on developing a solution that effectively integrates traditional firefighting methods with autonomous technologies, ensuring a comprehensive response to fire incidents.

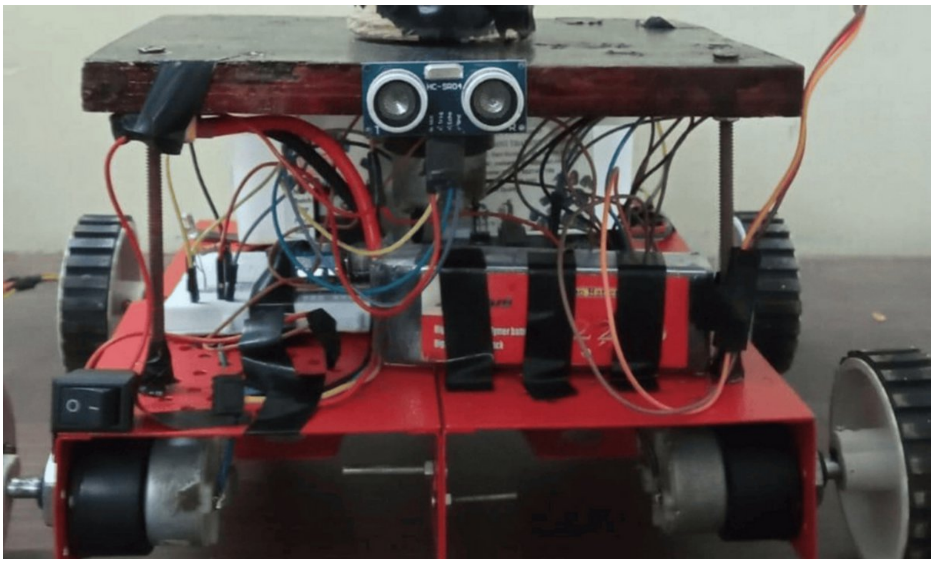

FIGURE 2: Image to represent the firefighting robots with AI-driven system for extinguishing the fire

The suggested innovative solution to address this issue encompasses two main components. Firstly, during field operations, the robot will engage in data collection, transmitting gathered information to the user. Secondly, employing predetermined algorithms, the robot will analyze the data and execute actions accordingly. The core objective of this project is twofold: to mitigate both commercial and human losses resulting from fire accidents, while simultaneously enhancing the precision of firefighting endeavors. Furthermore, it aims to offer a viable alternative to traditional firefighting methods, potentially replacing human firefighters with advanced technological solutions.

The structure of this review paper will adhere to a logical progression. It will commence by delineating conventional firefighting methodologies, subsequently transitioning to the application of AI and Machine Learning (ML) techniques to tackle the identified problem. Following this, the paper will elucidate the technologies employed and expound upon the operational workflow of the robot. This review paper will prominently focus on comparing and analyzing the existing solution along with a suggested modern approach with AI and Internet of Things (IoT). Finally, the paper will conclude with the conclusions and future scope.

Background

In the domain of firefighting, the fusion of ML and Deep Learning techniques presents a promising avenue for revolutionizing traditional firefighting practices. This review explores the convergence of ML technology with firefighting methodologies, shedding light on their combined potential to augment fire detection, prediction, and response mechanisms [9]. While existing literature predominantly focuses on algorithmic advancements, this paper uniquely extends this discourse by emphasizing the imperative of practical implementation, thereby bridging the gap between theoretical frameworks and real-world firefighting applications.

In a recent study, Mukhiddinov et al. [10] addressed the limitations of traditional sensor-based fire detection systems, highlighting the constraints imposed by predefined distance thresholds. Their review underscores the transformative potential of AI, particularly deep learning techniques such as YOLO, in revolutionizing fire detection capabilities. Notably, Mukhiddinov et al.'s exploration primarily focuses on algorithmic advancements rather than practical implementation aspects. The literature presents promising algorithmic frameworks [10].

The paper "Fire Detection Using Image Processing" by Swarajya Lakshmi [11] introduces a novel approach to address the limitations of traditional fire detection systems. It employs advanced image processing techniques, including the YOLO v3 model, for efficient fire detection, particularly in scenarios where flames are obscured by smoke. The research involves custom dataset creation, model training using Darknet on Google Colab, and evaluation against benchmark datasets [11].

In the paper "CeaseFire: The Fire Fighting Robot" by Mittal et al. [12], CeaseFire appears to be manually controllable rather than incorporating ML algorithms for autonomous operation. It relies on a remote-control system developed to control its movements and firefighting actions. While it integrates various sensors for temperature monitoring, air quality assessment, and real-time video feed, there is no indication of ML algorithms being utilized for decision-making or autonomous navigation. Thus, CeaseFire seems to rely on human operators for guidance and control during firefighting operations [12].

The paper "Image Fire Detection Algorithms Based on Convolutional Neural Networks" by Li and Zhao [13] emphasizes the importance of early fire detection in reducing losses and addresses limitations of traditional methods. It introduces image fire detection as a promising solution, leveraging convolutional neural networks (CNNs) for accurate feature extraction. The study proposes enhancements to address challenges such as region proposal determination and computational efficiency. Evaluation of four advanced CNN-based algorithms demonstrates significant improvements in detection performance, promising better fire prevention strategies than earlier methods [13].

Patel and Pancholi [14] worked on a fire extinguishing robotic vehicle controlled via an Android app. While smartphone-controlled systems offer intuitive remote operation, they face challenges in optimizing sensor accuracy and navigation in hazardous environments. Notably, visibility issues in smoky conditions pose a major drawback to user control, making it inefficient in smoky environments [14].

Review

Introduction to firefighting challenges

Firefighting in high-risk environments, such as industrial facilities, poses considerable threats to the lives of the firefighters. The major challenge here includes raging fires, caused by flammable materials, chemicals, or explosive substances, which spread rapidly and intensify before effective firefighting teams can respond. Another great danger is from the intense heat of the gigantic fires, which limits the amount of time that firefighters can remain close to the fire. Toxic gases and the hazardous chemical emissions from industrial fires expose firefighters, even when they are wearing protective gear, to the dangers of inhalation injury and long-term health effects [1,15]. It has also emerged that structural instability is another massive threat as the fire weakens buildings, making them vulnerable to collapse on them. There is a threat of falling debris and getting entrapment inside the burning building on the firefighters' side.

The rest comprise poor visibility resulting from thick smoke, making navigation difficult for the firefighters or locating the source of the fire or victims. Limitations of access to the fire will be experienced in industrial and urban areas due to obstacles of machinery, locked doors, or misleading building layout. Resource constraints, for instance, lack of water or firefighting apparatus/equipment, more so in remote areas, delay response and containment efforts. In huge fire outbreak cases, various teams must coordinate; however, communication, noise, or equipment failure may make it more confusing with errors. Such conclusions indicate the need for improved firefighting technologies, higher safety protocols, and adequate resource management that could improve response efforts and ensure the safety of firefighters while they work in high-risk scenarios [1,16].

Different methods of firefighting

Firefighting technologies have evolved over centuries, adapting to the changing nature of fires and the environments in which they occur. Early methods were rudimentary, relying on manual efforts and basic tools. The historical progression of firefighting technologies showcases a continual quest to enhance effectiveness, reduce risks, and protect both life and property (Table *1*) [5].

Hand-Pumped Fire Engines

The 17th century saw the introduction of hand-pumped fire engines, a significant advancement in firefighting technology. These engines allowed for a more organized and sustained water supply, enabling firefighters to direct water into flames with greater force [17].

Steam-Powered Fire Engines

The 19th century brought about steam-powered fire engines, marking a transformative shift. Steam engines offered increased pumping capacity and mobility, allowing firefighting teams to respond more effectively to incidents in urban areas [18].

Fire Hydrants

The installation of fire hydrants in the late 19th century further improved water accessibility. This infrastructure allowed firefighters to tap into the municipal water supply, reducing dependence on external water sources [19].

Motorized Fire Apparatus

The early 20th century witnessed the advent of motorized fire apparatus, replacing horse-drawn vehicles. This development significantly enhanced response times, enabling faster deployment of firefighting equipment [17].

Computer-Aided Fire Modeling

In the latter half of the 20th century, computer technology began influencing firefighting strategies. Computer-aided fire modeling allowed for better predictions of fire behavior, aiding in strategic planning and risk assessment (Figure *3*) [20].

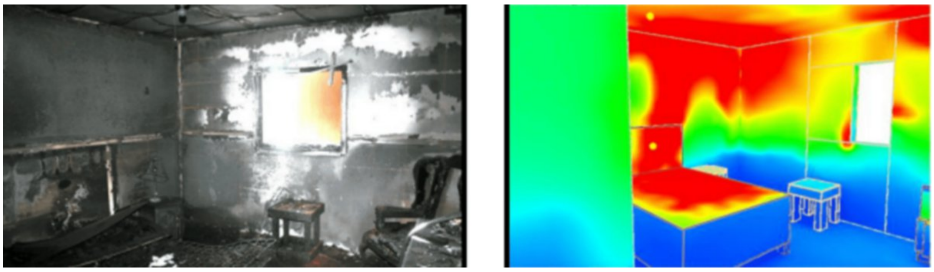

FIGURE 3: Visualization of robot-based firefighting scenario

Integration of robotics and remote sensing

Recent decades have seen the integration of robotics and remote sensing technologies in firefighting. Unmanned Aerial Vehicles equipped with cameras and sensors provide aerial views, aiding in situational awareness and decision-making (Figure *4*) [7,21].

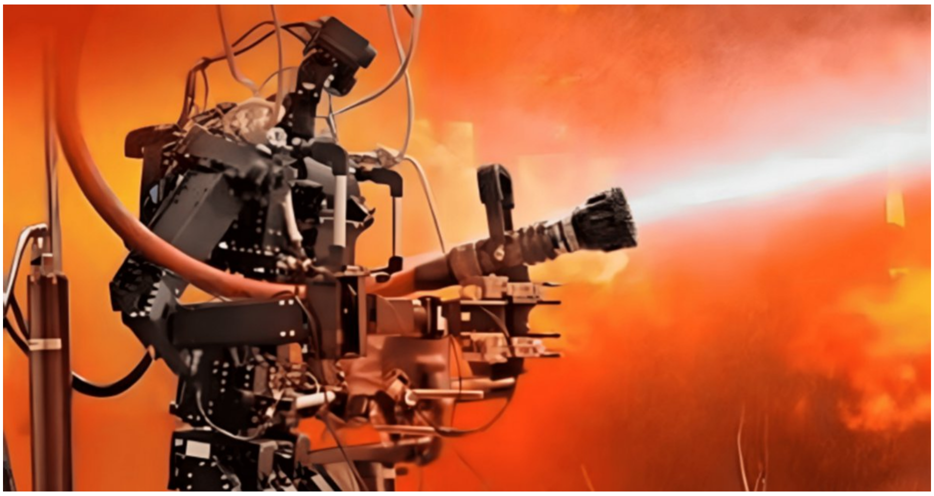

FIGURE 4: Autonomous firefighting robot

As we delve into the 21st century, the exploration of AI and IoT technologies promises a new frontier in firefighting. The proposed autonomous fire-extinguishing robots represent the latest chapter in this ongoing narrative, aiming to redefine the capabilities of firefighting technologies and enhance safety in the face of evolving challenges [3,22].

Aspect	Traditional Methods	Autonomous Robot
Early Detection	Manual observation	Sensor data analysis
Response Time	Time taken to mobilize firefighters	Instant response
Risk to Firefighters	High	Minimal
Effectiveness	Dependent on human intervention	AI-driven decision-making
Cost	Equipment and manpower costs	Initial setup vs. long-term maintenance

TABLE 1: Table of the comparison of traditional firefighting methods versus autonomous robots

Impacts of AI-ML in firefighting

AI-ML has emerged as a transformative force in firefighting, offering innovative solutions to enhance early detection, decision-making, and overall operational efficiency. The applications of AI-ML in firefighting encompass various aspects, each contributing to a more effective and proactive approach to fire management [9,16].

Early Fire Detection

AI-ML algorithms play a pivotal role in early fire detection systems. ML models analyze sensor data, such as smoke patterns and temperature changes, to identify potential fire incidents at their nascent stages. This proactive approach enables swift responses, minimizing the escalation of fires [3,23].

Predictive Fire Behavior Modeling

ML is employed to model and predict fire behavior based on various parameters, including weather conditions, fuel types, and topography. These predictive models assist firefighting teams in anticipating fire growth patterns, enabling more informed decision-making regarding evacuation routes, resource allocation, and strategic planning [24].

Decision Support Systems

AI-ML-driven decision support systems aid firefighting commanders in making informed choices during emergencies. These systems integrate real-time data from sensors, weather forecasts, and historical fire behavior models to provide actionable insights. This enhances the efficiency of resource deployment and improves overall incident management [25].

Intelligent Monitoring and Alert Systems

ML is integrated into monitoring systems that continuously analyze sensor data from various sources. Intelligent algorithms distinguish between normal activities and potential fire indicators, reducing false alarms and enhancing the accuracy of alert systems. This ensures timely responses without unnecessary disruptions [26].

Firefighter Health and Safety Monitoring

Wearable devices equipped with AI-ML capabilities monitor the health and safety of firefighters in real time. These devices analyze vital signs, environmental conditions, and physiological parameters to provide early warnings for potential health risks. AI-ML algorithms contribute to predictive analytics, enabling preventive measures to ensure firefighter well-being [27].

Smart Firefighting Equipment

AI-ML is integrated into firefighting equipment, such as smart hoses and nozzles. These devices use real-time data to optimize water flow, adapt to changing fire conditions, and improve the efficiency of extinguishing efforts. AI-ML-driven equipment enhances precision and control in firefighting operations [9,16].

Post-Incident Analysis and Learning

AI-ML facilitates post-incident analysis by processing data from firefighting operations. This analysis aids in understanding the effectiveness of strategies employed, identifying areas for improvement, and enhancing the overall learning process for future incidents [20].The integration of AI-ML technologies in firefighting reflects a paradigm shift in how we approach fire management. By leveraging the capabilities of AI, firefighting operations become more proactive, data-driven, and technologically advanced, ultimately leading to improved safety outcomes and more efficient resource utilization [19,20].

IoT sensors used in hardware implementation

1. Ultrasonic Sensors: Obstacle Detection and Mapping

2. Lidar Technology: Mapping and Navigation

3. Gas Detectors: Early Detection of Hazardous Gases

4. Smoke Detectors: Early Detection of Smoke

5. Cameras: Visual Data Acquisition and Remote Control

6. Microcontrollers: Control and Coordination

7. Temperature and Heat Sensors: Fire Severity Assessment

8. Humidity Sensors: Environmental Monitoring

These sensors form a networked ecosystem that empowers firefighting teams with real-time information, enhancing situational awareness and enabling more efficient responses to fire incidents.

Key features of the idea

Data Fusion and Analysis

- ML algorithms analyze data from various IoT sensors [22].

- Integration enhances accuracy in fire detection and situational awareness [1].

Predictive Analytics for Fire Behavior

- AI models predict fire behavior using historical and real-time IoT data [24].

- Enables anticipation of fire progression and optimization of resource allocation [17].

Autonomous Fire-Extinguishing Robots

- AI algorithms in robots navigate environments and execute tasks autonomously [9].

- Utilize data from ultrasonic, lidar, and camera sensors for real-time decision-making.

Remote Monitoring and Control

- IoT enables real-time remote monitoring of firefighting operations [28,29].

- AI processes data from sensors, providing insights and facilitating remote control [19].

Adaptive Resource Allocation

- AI-driven decision support systems optimize resource allocation based on sensor inputs [25].

- Ensures effective response strategies in dynamic fire incidents.

Edge Computing for Real-Time Processing

- Edge computing processes sensor data on-site, reducing latency.

- AI algorithms at the edge enhance efficiency in data processing and response times [29,30].

Environmental Monitoring for Firefighter Safety

- IoT sensors monitor environmental conditions in real time [30].

- AI analyzes data to provide early warnings for hazardous conditions, ensuring firefighter safety.

Continuous Learning and Optimization

- AI models learn from historical data to improve predictions and decision-making [31].

- Enables continuous optimization of firefighting strategies based on past incidents.

ML/DL algorithms

Image Processing and Fire Detection

Image classification can be accompanied with feature extraction through the implementation of CNNs. Some of the common architectures are as follows:

ResNet: Very effective for deeper networks while improving performance.
VGGNet: This architecture is good for image recognition tasks.
MobileNet: Lightweight model optimized for real time on embedded systems.

Sensor Data Analysis

Random forests: Useful in classifying fire conditions from sensor data (smoke, temperature, humidity).
Support vector machine: This algorithm can be used to classify whether the environmental conditions indicate a fire.

Decision-Making for Fire Extinguishing

Reinforcement learning: Particularly using Deep Q-Network or Proximal Policy Optimization algorithms. Provided with real-time feedback from the environment, such reinforcement learning decides on the optimal action like where and how to douse the fire.

Real-Time Integration of Image Data With Sensor Data

Multimodal deep learning techniques: Methods that bring together CNNs for image data and other models such as LSTMs or GRUs for sequential sensor data whereby the bot can make informed decisions based on two forms of input.
Ensemble learning: Combining different models (CNNs for images and RF for sensor data) to improve overall accuracy and robustness in the detection of fires.

Edge Computing for Processing

Tiny YOLO: A light version of YOLO, this one is more suited for the edge devices that do its proper object detection in real time. Images are processed on the edge device as quickly as possible in the firefighter bot.

FLOW

Strategic Bot Deployment

Deploy the bot strategically in the target area, considering factors such as topography, potential fire-prone zones, and areas with high human activity. Utilize a combination of sensors, including ultrasonic for distance measurement, Lidar for precise mapping, and gas/smoke detectors for early fire detection [1]. The deployment strategy should be adaptable to the specific characteristics of the environment, ensuring optimal coverage.

Efficient Data Handling

Develop a robust data collection system that integrates cameras and microcontrollers for real-time monitoring. Ensure the seamless transmission of collected data to the operator for further analysis by employing efficient communication protocols [9]. Implement data storage mechanisms with redundancy to prevent data loss and enable retrieval for post-incident analysis.

Real-Time Simulation and Abnormality Detection

Utilize real-time simulation software to analyze incoming data promptly. Implement algorithms that can identify abnormal patterns or outliers in the sensed information, enabling the system to differentiate between regular environmental variations and potential fire events (Figure *5*). This proactive approach enhances the accuracy of the monitoring system [25,32].

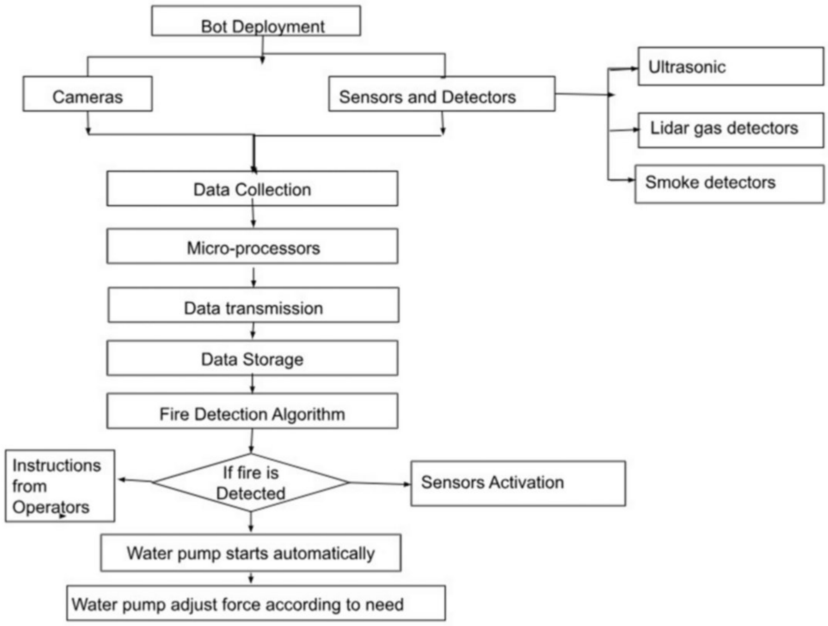

FIGURE 5: Flowchart showing bot deployment phase

Image Processing for Fire Confirmation

Develop an advanced image processing algorithm for precise fire confirmation. Incorporate techniques such as histogram equalization to enhance image contrast, contrast adjustment for improved visibility, and a threshold function for isolating the red component indicative of fire [2]. Additionally, implement ML algorithms for pattern recognition to further refine the accuracy of fire event identification [25,32].

Automated Response System

Integrate an automated response system that goes beyond basic fire detection. Upon fire confirmation, provide the operator with detailed instructions for effective decision-making, including the exact location of the fire and the shortest path to reach the target area. Automate the initiation of the water pump motor and dynamically adjust water force through servo and stepper motors based on real-time requirements, optimizing firefighting efforts [8,33].

Comprehensive Monitoring and Mapping

Enhance comprehensive monitoring by incorporating GPS coordinates into the mapping process, providing the operator with accurate location information. Implement a system that captures real-time images through designated checkpoints, allowing for a visual understanding of the affected zone. Integrate technologies such as augmented reality for overlaying critical information onto the operator's view, facilitating more informed and effective decision-making during firefighting operations [34].

Conclusions

Conclusively, with the incorporation of advanced technologies such as microcontrollers and sensors into fire safety systems, it is a promising way of mitigating the disastrous influence of fires in high-rise apartments. The innovative approach here allows early detection through real-time monitoring and AI, together with precise control over a possible fire incident, which may quite possibly minimize possible losses. The risks while working in dangerous conditions with human firefighters alone are a huge risk, but the autonomous firefighting robots could mitigate those risks. With advanced sensors and powered through microcontrollers, these robots work in coordination with, or in lieu of, traditional methods to better improve situational awareness and create proactive plans for firefighting purposes. They ensure proper response to hazardous environments and safeguard occupants as well as emergency responders. This is realized in emphasizing the combination of robotic systems with the traditional non-robotic firefighting efforts to yield an all-rounded response to emergencies. Additionally, there are more studies focused on either fully autonomous robots or manual approaches in handling fires, with minimal focus on the advantages that come with the hybrid techniques. The present study fills this gap through the proposal of a review on dual-operational firefighting robots that make use of strengths from both approaches, thus better ensuring safety and efficiency in situations involving high-rise buildings.

In short, the approach outlined here represents a new paradigm for fire safety, dealing with some of the special dilemmas of fires in tall buildings. This could be done by leveraging the capacities of microcontrollers, sensors, and autonomous firefighting robots in such environments to ensure a minimum amount of loss and protect both occupants and responder welfare.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Amey G. Medewar, Ankush D. Sawarkar

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Drafting of the manuscript: Amey G. Medewar, Ankush D. Sawarkar, Utkarsh V. Kshirsagar

Critical review of the manuscript for important intellectual content: Ankush D. Sawarkar

Supervision: Ankush D. Sawarkar

Disclosures

Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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References

1. Kodur V, Kumar P, Rafi MM: Fire hazard in buildings: review, assessment and strategies for improving fire safety. PSU Research Review. 2020, 4:1-23. 10.1108/prr-12-2018-0033
2. Neogi C, Manna M: Fires in India: learning lessons for urban safety. National Institute of Disaster Management (NIDM), Ministry of Home Affairs, Government of India. (2020). https://nidm.gov.in/PDF/pubs/Fires_in_India_2020.pdf.
3. Ramasubramanian S, Muthukumaraswamy SA, Sasikala A: Fire detection using artificial intelligence for fire-fighting robots. 2020 4th International Conference on Intelligent Computing and Control Systems (ICICCS). 2020, 1:180-185. 10.1109/ICICCS48265.2020.9121017
4. Madhevan B, Sakkaravarthi R, Singh GM, Diya R, Jha DK: Modelling, simulation and mechatronics design of a wireless automatic fire fighting surveillance robot. Defence Science Journal. 2017, 67:572-580. 10.14429/dsj.67.10237
5. Vidyadharan A, John J, Thomas C, Yadav BP: Fire safety management in India: a review. Advances in Fire and Process Safety. Springer Transactions in Civil and Environmental Engineering. Siddiqui N, Tauseef S, Abbasi S, Rangwala A (ed): Springer, Singapore; 2018. 1:171-181. 10.1007/978-981-10-7281-9_14
6. Avazov K, Hyun AE, Sami S AA, Khaitov A, Abdusalomov AB, Cho YI: Forest fire detection and notification method based on AI and IoT approaches. Future Internet. 2023, 15:61. 10.3390/fi15020061
7. Roldán-Gómez JJ, González-Gironda E, Barrientos A: A survey on robotic technologies for forest firefighting: applying drone swarms to improve firefighters' efficiency and safety. Applied Sciences. 2021, 11:363.

10.3390/app11010363
8. Rambabu K, Siriki S, Chupernechitha D, Pooja Ch: Monitoring and controlling of fire fighthing robot using IOT. International Journal of Engineering Technology Science and Research. 2018, 5:552-557.
9. Jiao Z, Zhang Y, Xin J, Mu L, Yi Y, Liu H, Liu D: A deep learning based forest fire detection approach using UAV and YOLOv3. 2019 1st International Conference on Industrial Artificial Intelligence (IAI). 2019, 1:1-5. 10.1109/ICIAI.2019.8850815
10. Avazov K, Mukhiddinov M, Makhmudov F, Cho YI: Fire detection method in smart city environments using a deep-learning-based approach. Electronics. 2021, 11:73. 10.3390/electronics11010073
11. Swarajya Lakshmi B: Fire detection using image processing. Asian Journal of Computer Science and Technology. 2021, 10:14-19. 10.51983/ajcst-2021.10.2.2883
12. Mittal S, Rana MK, Bhardwaj M, Mataray M, Mittal S: CeaseFire: the fire fighting robot. 2018 International Conference on Advances in Computing, Communication Control and Networking (ICACCCN). 2018, 1:1143-1146. 10.1109/ICACCCN.2018.8748547
13. Li P, Wangda Z: Image fire detection algorithms based on convolutional neural networks. Case Studies in Thermal Engineering. 2020, 19:100625. 10.1016/j.csite.2020.100625
14. Patel K, Pancholi BK: A novel fire extinguishing robotic vehicle controlled by android application. 2017 IEEE International Conference on Smart Technologies and Management for Computing, Communication, Controls, Energy and Materials (ICSTM). 2017, 1:417-422. 10.1109/ICSTM.2017.8089196
15. Kang Q, Ma B: Research on fire-safety assessment of high-rise building based on the fuzzy centralization theory. 2010 Seventh International Conference on Fuzzy Systems and Knowledge Discovery. 2010, 1:1349-1354. 10.1109/FSKD.2010.5569095
16. Sharma A, Singh PK, Kumar Y: An integrated fire detection system using IoT and image processing technique for smart cities. Sustainable Cities and Society. 2020, 61:102332. 10.1016/j.scs.2020.102332
17. Meng H, Xiao L, Zhang C, Zhang T, Xia D, Dong W: A systematic review and bibliometric analysis of electrical fires from 1993 to 2022. Fire Technology. 2024, 60:3347-3377. 10.1007/s10694-024-01580-2
18. Sarkar S, Debnath A: Green IoT: design goals, challenges and energy solutions. 2021 6th International Conference on Communication and Electronics Systems (ICCES). 2021, 1:637-642. 10.1109/ICCES51350.2021.9489167
19. Owayjan M, Freiha G, Achkar R, Abdo E, Mallah S: Firoxio: forest fire detection and alerting system. MELECON 2014 - 2014 17th IEEE Mediterranean Electrotechnical Conference. 2014, 1:177-181. 10.1109/MELCON.2014.6820527
20. Mukhiddinov M, Abdusalomov AB, Cho JA: A wildfire smoke detection system using unmanned aerial vehicle images based on the optimized YOLOv5. Sensors. 2022, 22:9384. 10.3390/s22239384
21. Suresh J: Fire-fighting robot. 2017 International Conference on Computational Intelligence in Data Science (ICCIDS). 2017, 1:1-4. 10.1109/ICCIDS.2017.8272649
22. Basu MT, Kartihk R, Mahitha J, Reddy VL: IoT based forest fire detection system. International Journal of Engineering & Technology. 2018, 7:124-126.
23. Sharma R, Rani S, Memon I: A smart approach for fire prediction under uncertain conditions using machine learning. Multimedia Tools and Applications. 2020, 79:28155-28168. 10.1007/s11042-020-09347-x
24. Muhammad K, Ahmad J, Baik SW: Early fire detection using convolutional neural networks during surveillance for effective disaster management. Neurocomputing. 2018, 288:30-42. 10.1016/j.neucom.2017.04.083
25. Kim B, Lee J: A video-based fire detection using deep learning models. Applied Sciences. 2019, 9:2862. 10.3390/app9142862
26. Jabbar WA, Kian TK, Ramli RM, et al.: Design and fabrication of smart home with internet of things enabled automation system. IEEE Access. 2019, 7:144059-144074. 10.1109/access.2019.2942846
27. Pandey H, Prabha S: Smart health monitoring system using IOT and machine learning techniques. 2020 Sixth International Conference on Bio Signals, Images, and Instrumentation (ICBSII). 2020, 1:1-4. 10.1109/ICBSII49132.2020.9167660
28. Vinodhini V, Kumar MRS, Sankar S, Pandey D, Pandey BK, Nassa VK: IoT-based early forest fire detection using MLP and AROC method. International Journal of Global Warming. 2022, 27:55-70. 10.1504/ijgw.2022.122794
29. Sawarkar AD, Shrimankar DD, Singh L, Agrahari A, Lachure S, Bokde ND: Commercial Indian bamboo species classification on MatK DNA barcode sequences using machine learning techniques with K-Mer. 2023 International Conference on Computer, Electronics & Electrical Engineering & their Applications (IC2E3). 2023, 1:1-6. 10.1109/IC2E357697.2023.10262781
30. Al Hasani IMM, Kazmi SIA, Ali Shah R, Hasan R, Hussain S: IoT based fire alerting smart system. Sir Syed University Research Journal of Engineering & Technology. 2022, 12:46-50. 10.33317/ssurj.410
31. Sawarkar AD, Shrimankar DD, Sahu SK, Singh L, Bokde ND, Kumar M: Commercial clustering of Indian bamboo species using machine learning techniques. 2023 2nd International Conference on Paradigm Shifts in Communications Embedded Systems, Machine Learning and Signal Processing (PCEMS). 2023, 1:1-5. 10.1109/PCEMS58491.2023.10136094
32. Kinateder M, Ronchi E, Nilsson D, Kobes M, Müller M, Pauli P, Mühlberger A: Virtual reality for fire evacuation research. 2014 Federated Conference on Computer Science and Information Systems. 2014, 1:313-321. 10.15439/2014F94
33. Perilla FS, Villanueva GR, Cacanindin NM, Palaoag TD: Fire safety and alert system using Arduino sensors with IoT integration. Proceedings of the 2018 7th International Conference on Software and Computer Applications. 2018, 1:199-203. 10.1145/3185089.3185121
34. Salhi L, Silverston T, Yamazaki T, Miyoshi T: Early detection system for gas leakage and fire in smart home using machine learning. 2019 IEEE International Conference on Consumer Electronics (ICCE). 2019, 1:1-6. 10.1109/ICCE.2019.8661990