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# Design and Implementation of an Autonomous Fire-Extinguishing Robot with SMS Alert Functionality

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## Abstract

*Fire outbreak represents a formidable threat, capable of causing loss of life, property destruction, and permanent injuries. Firefighters bravely confront these hazards, placing themselves at serious risk to protect communities. Despite the inherent dangers, their selfless service remains vital. Among recent technological advancements, firefighting robots have emerged as significant tools for mitigating such risks. These robots utilize machine learning and cutting-edge sensor technologies to enhance fire detection accuracy, minimizing false alarms. To improve the performance of the fire robot, this study designed and implemented an Arduino UNO microcontroller based on the ATmega32 and developed using C++ language. In addition to equipping it with SMS capability that allows it to notify the concerned entity about an outbreak, the developed robot operates autonomously thereby minimizing human error in its operation. With the aid of the ultrasonic sensors, the robot navigates and avoids obstacles collision with high precision. Integrated with flame and smoke sensors controlled by the microcontroller ensures swift fire detection. By autonomously sprinkling water from a mounted container, it effectively suppresses fires. Through this innovative design, the study aims to bolster fire response capabilities, reducing reliance on human intervention and enhancing safety for both firefighters and civilians. From the performance evaluation carried out on the developed robot, it was observed that the robot has exhibited an effective performance in detecting and extinguishing fires using the various sensors.*

### Nomenclature and units

| | |
|---|---|
| $MHz$ | Megahertz |
| $MS$ | Milliseconds |
| $\mu s$ | Microseconds |
| $cm$ | Centimetres |
| ℃ | Degree Celsius |

## 1.0 Introduction

Given that fire catastrophes pose a major threat to both human life and property, early fire detection is essential for safeguarding both. According to Owoeye et al. (2020), fire is the exothermic chemical process of fast oxidation of a substance that releases heat, light, and numerous reaction products. We all know that every fire starts with smoke and heat. As a result, firefighting systems have attracted the attention of many researchers. The automation of these systems, which will reduce the reliance of firefighting operations on human help, has received more attention.

An automated firefighting system, commonly used in industrial and commercial applications, relies on temperature and smoke-detecting equipment. However, it is important to note that sensible heat often occurs after significant damage has already been done, so the use of smoke sensors should not be neglected. Various types of fire detectors have been created for buildings. In the past, several algorithms have been developed to design or enhance firefighting robots (Mahajan et al., 2015). However, despite its quick response time, the smoke sensor has a high rate of false alarms. On the other hand, the temperature sensor provides more consistent results but takes longer to respond. Fire detectors with only one sensor may fail to activate when needed or generate false alarms. Therefore, a fire detection system that combines smoke and temperature sensors not only compensates for the limitations of the smoke sensor but also creates a more intelligent fire control system. Consequently, it is recommended to use a firefighting robot equipped with multiple sensors to detect fire.

Over time, firefighting has proven to be a challenging task for humans due to physical limitations and harsh conditions encountered during fire incidents. Firefighters face long and irregular working hours, high environmental temperatures, dust, low humidity, and even life-threatening situations such as explosions and collapsed structures. Current studies are being conducted on the use of robots in firefighting to reduce firefighter injuries and fatalities, while also improving productivity, safety, efficiency, and the overall quality of firefighting operations (Owoeye et al., 2020). Early detection of fires can be achieved through various means, such as a smoke and heat detector, while water sprinklers are the most commonly used method for extinguishing fires. An automatic fire sensing and extinguishing robot ensures the presence of a reliable fire detection and extinguishing system. The significance of the control unit in enhancing fire detection and control has long been recognized, with one of the two main types of intelligent fire detection systems utilizing a control unit for decision-making (Islam et al., 2016).

Extensive research has been dedicated to the development of autonomous robots for fire sensing and extinguishing purposes. Surya et al. (2019) created a Remotely Located Fire Extinguishing Robot that utilizes DTMF tones to control its wheels and maintain precise rotation angles. A DTMF decoder recognizes the tones and sends output to an Arduino microcontroller, which activates motors, adjusts shaft angles, and manages shaft speed. The robot sprays water on flames based on sensor data.

Olugboji et al. (2019) designed an improved firefighting robot equipped with two DC motors and a castor wheel for locomotion, as well as a DC water pump for spraying water. The robot is controlled wirelessly via Bluetooth communication between a motor control app on an Android phone and the robot's components. An Arduino microcontroller coordinates the desired operation, and the entire system is powered by a 12V rechargeable battery. The robot can extinguish a simulated fire within 5 to 10 seconds.

Swati et al. (2020) developed a smart multimodal wireless firefighting robot capable of moving in multiple directions. Light-sensitive resistors are employed for flame detection, ensuring even minor flames are detected. Argel et al. (2020) introduced a 4-wheeled fire extinguishing robot with human presence identification capabilities, utilizing Wi-Fi remote operation and a camera for surveillance. Ultra-wideband radar (UWB) and the X4M300 presence sensor are used to detect human presence based on respiratory movement, achieving high accuracy.

Owoeye et al. (2020) proposed a robot designed for fire detection and extinguishing, equipped with a smoke sensor, IR flame sensor, and ultrasonic sensor for obstacle avoidance. The Arduino Mega microcontroller interfaces the sensing and actuating devices, while the L298N motor driver controls the robot's movement. Anuradha et al. (2021) developed a dual-mode fire extinguisher robot with automatic and manual operation modes, monitored and controlled by an Arduino UNO microcontroller.

These research efforts have employed various methods, including camera-based fire detection, machine learning techniques, thermal sensors, Bluetooth connectivity, IoT development, different navigation methods, and multiple microcontrollers. However, certain limitations have been identified, such as low configuration leading to reduced efficacy, reliance on human involvement, and the absence of a notification module to alert authorities. To address these issues and enhance the precision and output of fire-sensing and extinguishing robots, further improvements are being pursued based on the existing methodologies.

An automatic fire-sensing and extinguishing robot can benefit any facility that faces the risk of fire outbreaks, including homes, gas stations, companies of all sizes, warehouses, school campuses, airports, and hospitals, among others. In Nigeria, firefighting systems are primarily operated manually, which often proves ineffective as fires are not detected early enough. Additionally, firefighters may struggle to access hard-to-reach areas that require fire extinguishing. The main issue lies in the manual operation of these systems, particularly when they are located inside a building, making them challenging to use during fires. An efficient system that detects fire parameters, issues auditory warnings, activates water sprinklers, and notifies relevant authorities is crucial for fire prevention. This paper describes the development of an autonomous fire-sensing and extinguishing robot with the capability to send SMS messages or make phone calls for notification purposes.

The remainder of the paper is organized as follows: Section 2 provides background information and discusses related work on fire-extinguishing robots. Section 3 explains the methodology employed in the development of the fire-extinguishing robot. The performance evaluation is presented in Section 4. Finally, Section 5 concludes the paper and suggests future work.

## 2.0 Background of the Study

This section presents the background of fire-sensing and extinguishing robots.

### 2.1 Autonomous Rescue Robots

The quest for autonomous systems is comparable to the ultimate goal in robotics and artificial intelligence research. Autonomous rescue robots play a crucial role in search and rescue operations, reducing the risks faced by human rescuers during catastrophic events. Equipped with advanced sensors, intelligent algorithms, and robust mobility, these robots are vital in disaster response and recovery. Their ability to navigate challenging terrain and access hazardous spaces surpasses that of human rescuers. With a range of sensors, including cameras, lidar, and infrared detectors, these robots can perceive their surroundings and identify potential hazards (Wang et al., 2021).

Cutting-edge mobility technologies enable autonomous rescue robots to manoeuvre across various surfaces and overcome obstacles using wheels, tracks, or even legs, depending on the requirements of the task (Chen et al., 2020). This mobility allows them to reach survivors in hard-to-access areas and provide assistance. Another key feature of autonomous rescue robots is their ability to assess and evaluate individuals. By analyzing sensor data and employing artificial intelligence and machine learning, these robots can detect human features or signs of life, prioritizing areas for search and rescue operations. This significantly enhances the efficiency of rescue missions by assisting human rescuers in locating areas with a higher likelihood of finding survivors (Ma et al., 2019).

Moreover, autonomous rescue robots are often equipped with manipulators and tools to perform various tasks during rescue operations. They can remove debris, transport supplies, and even provide basic medical care to survivors (Sugiura et al., 2018). These capabilities automate a range of activities, relieving the burden on human responders and improving overall operational efficiency. Establishing effective communication networks is also crucial for autonomous rescue robots. These robots are equipped with robust communication systems that allow them to transmit real-time data and video feeds to a control centre. This enables human operators to monitor the robot's actions, assess the situation remotely, and take appropriate measures (Zheng et al., 2019).

### 2.2 Fire Sensing Techniques

This section presents four main fire sensing techniques which are infrared imaging, ultraviolet detection, smoke detection, and gas sensors.

**Infrared (IR) Imaging**: By detecting the radiation released in the infrared spectrum, IR sensors may identify the presence of fires. IR imaging-based flame detectors can discriminate between various kinds of flames and offer early fire detection.

**Ultraviolet (UV) Detection**: UV flame detectors make use of UV radiation-sensitive sensors. Even in hazy or occluded conditions, they can immediately locate flames.

**Smoke Detection**: Systems for detecting fire frequently employ smoke detectors. When smoke is present, they may detect it and set off an alarm or alert.

**Gas sensors**: Gases like carbon monoxide and carbon dioxide are frequently produced by a fire. These gases may be detected using gas sensors, which can also indicate.

### 2.3 Fire Extinguishing Techniques

This section explains the techniques relevant to fire detection and extinguishing. The techniques include:

**Water-Based Systems:** Sprinkler systems and other water-based fire extinguishing systems are frequently employed. To lessen the heat and put out the fire, they spray water on it.

**Foam Systems:** Foam fire suppression systems spread a layer of foam over the fire to smother it by blocking oxygen from reaching the flames.

**Powder-Based Systems:** Dry chemical extinguishers put out flames by using powdered materials like dry powder or ABC powder. These powders function by halting the chemical processes taking place in the fire.

**Carbon Dioxide (CO2) Systems:** By displacing oxygen, CO2 fire suppression systems successfully put out the flames. They are frequently utilized in locations where harm might be caused by water or other extinguishing agents.

### 2.4 Fire Sensing and Extinguishing Technologies

The world is changing for everyone, not just firefighters. We witness technology infiltrating practically every aspect of our lives all around us. Recognizing that technology is all around us, the SMARTER project has concentrated on how technology, particularly wearable or readily carried technology, may aid improve firefighter health and safety. This technology includes smart drones, Virtual Reality (VR systems), autonomous fire extinguishing robots, personal location equipment, cloud computing, smart jackets and lots more. These are briefly described subsequently.

**Firefighting Drones:** In the field of public safety, drones are becoming increasingly popular. According to the Center for the Study of the Drone at Bard College, nearly 350 state and local police, fire, and emergency service units had purchased drones as of April 2017. Drones can also be used for search and rescue operations by firefighters. Drones can search big areas fast. They may even be able to bring food, water, and first-aid supplies to areas where firemen are unable to reach. However, the agency must create a program with detailed policies for firefighting drones to be effective.

**Personal Location Equipment:** Firefighter accountability is crucial on the scene of an incident. Commanders must be aware of where each firefighter is always. This is especially true in the event of an unanticipated occurrence such as a structural collapse. It can mean the difference between life and death if a fireman is injured or trapped. It may be difficult to pinpoint the exact location of firefighters, and fire technology such as radios and GPS can be unreliable inside structures. However, current fireman technology employs more effective tracking methods in a variety of ways. Firefighters carry tiny gadgets that send their exact location to a command system in many of these situations.

**Cloud Computing:** Cloud-based technology can assist fire departments make sense of the rising quantity of data streaming in from sensors, drones, and mobile devices, which can be immensely useful in anticipating fire dynamics, improving response times, and more. Many of the programs have data-analysis components that indicate big-picture trends, challenges, and hazards. PowerDMS, for example, is a cloud-based program that maintains all department data and vital information in one secure area. This reduces the chances of important documents being misplaced or damaged. It ensures that everything is current and available from any location.

**Smart Jackets:** Firefighter safety must include responsibility for firefighters' health in addition to protection from external risks. Overexertion or stress was responsible for 42 per cent of firefighter deaths in 2016. Fire departments are increasingly emphasizing firefighters' health, fitness, and wellness. Some companies are developing firefighter jackets that incorporate personnel tracking technology and sensors that monitor heart rate, temperature, and motion, as well as incorporate the latest fire-resistant fabrics. While there aren't many of these combination jacket technologies on the market just now, there are plenty of technologies that can help firefighters evaluate physical strains on the job (Power DMS, 2022).

**Machine Learning:** Fire can be spotted across a larger area using artificial intelligence. The Haar Cascade Classifier is a machine-learning technique that was designed to detect objects. When numerous fires were to be detected, the results produced using the Haar Cascade Classifier were not particularly accurate. To boost accuracy, transfer learning from a pre-trained YOLOv3 model was employed to train the model for fire detection (Ramasubramanian et al., 2020).

## 3.0 Methodology

In this paper, we present the development of a compact fire-extinguishing robot equipped with an SMS alert system. The robot is designed to raise an alarm within the building, send an alert message or make a phone call to a registered number, and effectively extinguish the fire. Its small size enables easy manoeuvrability in confined spaces. The integration of a flame sensor and a smoke sensor enables the robot to detect the presence of fire. This autonomous system demonstrates the ability to automatically identify fire locations and extinguish them by utilizing a stored mixture in a container mounted on top of the robot.

### 3.1 High-Level Model of the Proposed System

The provided architectural diagram presents a comprehensive overview of the system, illustrating the main components that will be manufactured for the product and their interfaces. These models are simple visual representations intended to facilitate understanding, analysis, communication, and decision-making. Figure 1 illustrates the high-level design of the detection system and its various modules. A brief description of each component follows.

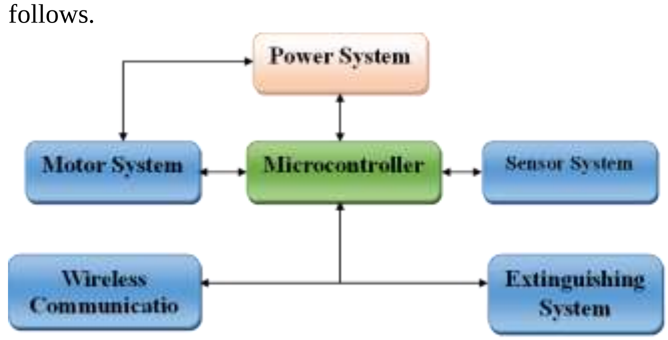


**Figure 1** High-Level Design of Fire Sensing and Extinguishing Robot.

**Power System:** This component includes the connection wires, batteries, power switch, and battery casing. It is responsible for the activation and deactivation of the robot by providing power.

**Microcontroller:** Serving as the core of the robot, the microcontroller is responsible for controlling, regulating, and enabling the interaction among different modules. In this research, an Arduino UNO microcontroller is employed.

**Motor System:** Consisting of the L293D motor driver, connection wires, and four wheels, the motor system facilitates the movement of the robot.

**Sensor System:** Comprising IR flame sensors and the MQ2 smoke detector, the sensor system is responsible for fire detection.

**Wireless Communication:** This module incorporates the GSM module and a SIM card, enabling the robot to notify the necessary authorities in the event of a fire outbreak.

**Extinguishing System:** Including the water tank, extinguishing material, servo motor, mini pump, and a nozzle, the extinguishing system is designed to extinguish the fire.

### 3.2 Data Flow Diagram of the Proposed System

The data flow diagram gives precise information about each entity's inputs and outputs, as well as the process itself as shown in Figure 2.

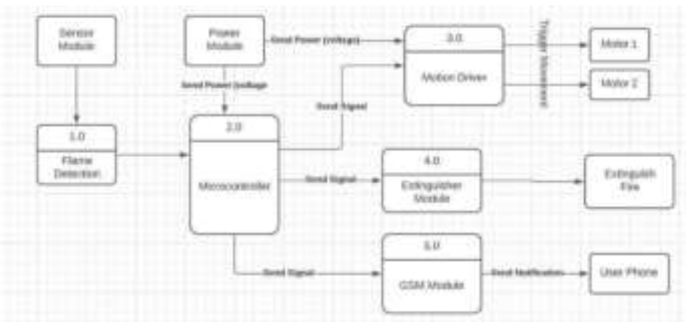


**Figure 2** Data Flow Diagram of Fire Sensing and Extinguishing Robot.

### 3.3 System Design

The system design in Figure 3 outlines the architecture, product engineering, modules, interfaces, and data necessary to fulfil specific requirements. Once the robot is powered on, the microcontroller and motor driver receive power. Subsequently, the microcontroller initiates the activation of sensors and other components. If a fire is detected, the sensors send signals to the microcontroller, prompting the robot to move towards the fire's location. The microcontroller then activates the extinguishing module and notification module, enabling the robot to extinguish the fire and alert the appropriate authorities.

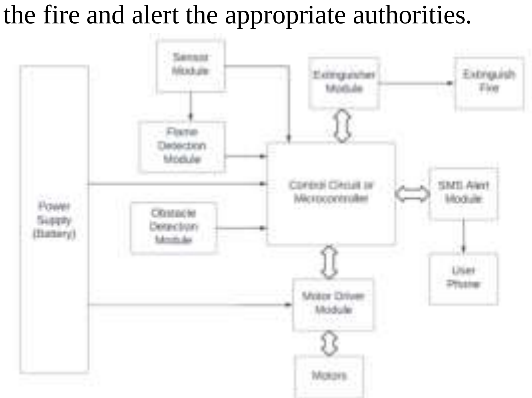


**Figure 3** System Design of the Fire Sensing and Extinguishing Robot.

### 3.4 Engineering Design

The unique workflows for electrical control system designers are addressed in electrical design. The circuit diagram of this research work is shown in Figure 4.

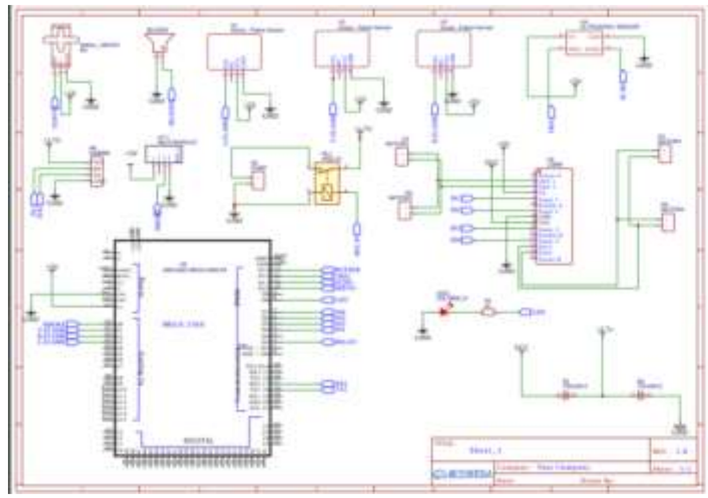

**Figure 4** Circuit Diagram of the Fire Sensing and Extinguishing Robot.

### 3.5 Proposed System Flowchart

The flowchart diagram for the algorithm of the fire sensing and extinguishing robot system is displayed in Figure 5.

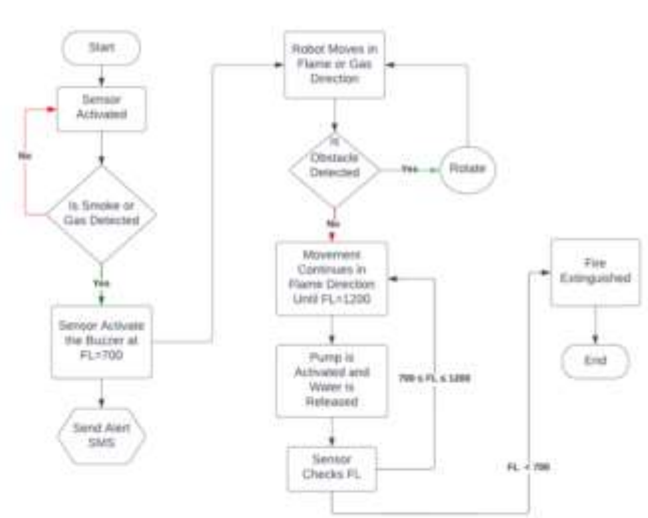


**Figure 5** The Flowchart for the Fire Sensing and Extinguishing Robot.

### 3.6 System Implementation

The system implementation describes the development process, procedures, and stages involved in creating the production system. The Fire Sensing and Extinguishing Robot's software and hardware components are categorized into the model, electrical component, and documentation. The primary programming code utilized for this project is C++ implemented in the Arduino IDE. The robot's implementation adopts a reinforcement learning technique, continuously scanning for fire once powered on, and activating the extinguishing and notification unit only when fire is detected. The robot generates a state, and the user determines whether to reward or penalize the model based on its output. The optimal solution is determined by the highest payoff. Figure 6 visually illustrates the implementation of the fire-sensing and extinguishing robot.

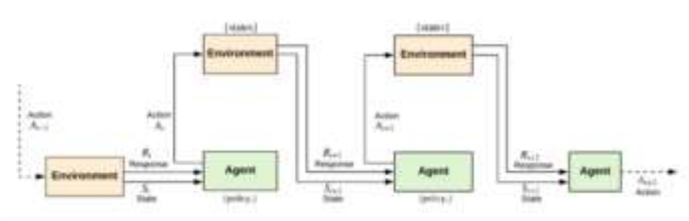


**Figure 6** Implementation of the Fire Sensing and Extinguishing Robot.

## 4.0 Results and Discussion

The performance evaluation and demonstration of the developed robot's fire extinguishing capabilities have been conducted. The robot has displayed effective performance in detecting and extinguishing fires using various sensors and specially designed fire extinguishing units. Additionally, it successfully notifies the relevant authorities through the SMS module.

To initiate the robot, the user simply powers on the system, and the robot autonomously carries out the sensing and extinguishing tasks. The system comprises several phases, including the power phase, sensing or detection phase, emergency notification phase, movement phase, and extinguishing phase. The hardware of the robot is powered by an Arduino UNO, a microcontroller board based on the ATmega328P. It features a 16 MHz quartz crystal, six analogue inputs, 14 digital input/output pins (with six being PWM outputs), a USB port, a power jack, an ICSP header, and a reset button. The Arduino UNO comes equipped with all the necessary components to support the microcontroller, requiring only a USB cable, AC-to-DC adapter, or battery for power. Figure 7 illustrates the user interfaces of the hardware system, showcasing the Arduino UNO Board, while Figure 8 provides a preview of the system.

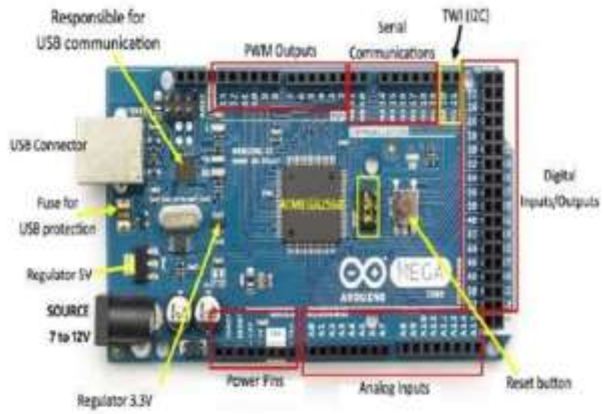


**Figure 7** The Arduino UNO Board.

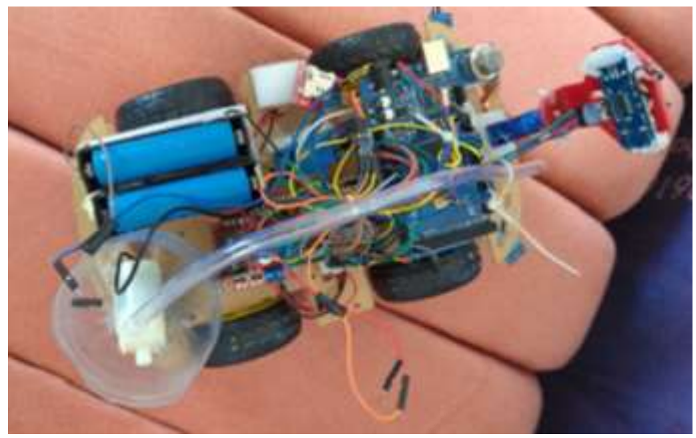

**Figure 8** Preview of the Fire Sensing and Extinguishing Robot.

## 5.0 Conclusions

Fire can occur unexpectedly in various locations, causing significant destruction, loss of life, and unforeseen expenses. Fire safety is crucial due to the potential dangers posed by fires, including smoke inhalation and exposure to hazardous chemicals. However, detecting fires in hard-to-reach or obscured areas can be challenging for humans.

In this paper, an autonomous robot for fire sensing and extinguishing was designed and developed. The robot utilizes flame sensors to identify fires and is equipped with ultrasonic sensors to avoid obstacles, ensuring the robot's safety and protection of its internal components. The Arduino microcontroller controls each sensor on the robot. In addition to the sensors, the robot is equipped with a water tank that supplies water upon fire detection. Upon activation, the robot autonomously moves throughout the room. When the flame sensors detect a fire, the robot moves towards the fire source and alerts the user. Upon reaching the fire location, the robot stops and extinguishes the fire using water. The robot's performance was evaluated in a controlled simulated environment with a low temperature, utilizing multiple functional sensors to minimize the risk of any malfunction in the alert circuit.

Future research on this project should focus on further enhancing the robot by incorporating advanced and larger-scale technological and electrical equipment to combat wildfires. Additional features that can be considered include: 1) integrating an LCD to provide information on fire status and severity, 2) enabling the robot to navigate staircases, 3) incorporating renewable energy sources like solar power to drive the main circuitry of the fire sensing and extinguishing system, and 4) integrating a GPS module to accurately transmit the robot's coordinates to relevant authorities. In addition to fire detection and extinguishing, other application areas the robot can fit in (though with some modifications) include nuclear radiation detection, underwater exploration, and more.

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## Declaration of conflict of interest

The authors have collectively contributed to the conceptualization, design, and execution of this paper. They have worked on drafting and critically revising the article to include significant intellectual content. This manuscript has not been previously submitted or reviewed by any other journal or publishing platform. Additionally, the authors do not have any affiliation with any organization that has a direct or indirect financial stake in the subject matter discussed in this manuscript.

## References

Anuradha, K., Prema, R., Revathy, N., Guhan, T., & Uma, K. P. (2021). An autonomous and intelligent flame sensing extinguishing robot. *2021 International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE)* (pp. 533-536). Greater Noida: IEEE. doi:10.1109/ICACITE51222.2021.9404677

Argel, A. B., Edwin, S., Jose, M. Z., Elmer, P. D., Gann, I. I., Rocez, D. J., & Chia-Yu, L. (2020). Human presence detection using ultra wide band signal for fire extinguishing robot. *2020 IEEE Region 10 Conference (TENCON)* (pp. 1176-1181). Osaka: IEEE. doi:10.1109/TENCON50793.2020.9293893

Chen, X., Deng, Y., Gao, J., & Guo, Y. (2020). Development of a legged robot for autonomous rescue in disaster environments. *IEEE Access*, *8*, 34353-34364.

Islam, A., Kaur, N., Ahmad, F., & Pichandi, S. (2016). Intelligent wireless fire extinguishing robot. International Journal of Current Engineering and Technology, 6(2), 520-526.

Ma, H., Li, P., Liu, H., & Huang, H. (2019). Deep learning-based autonomous robot for victim detection in disaster environments. *IEEE Access*, *7*, 165577-165585.

Mahajan, A., Singh, H., Nagarajan, S., Budhraja, V., Singh, S., Kumar, A., & Vashisht, A. (2015). Control of an autonomous industrial firefighting mobile robot. *DU Journal of Undergraduate Research and Innovation*, *2*, 1-5.

Olugboji, O., Jiya, J., & Ogwuche, I. (2019). Prototyping of a robotic fire vehicle using radio frequency technology. *FUOYE Journal of Engineering and Technology*, *4*, 17-21. doi:10.46792/fuoyejet.v4i1.260

Owoeye, S. O., Olaonipekun, O., Akinade, A. Emele, B. (2020). Development of a fire extinguishing robot with SMS alert capabilities. Journal of Advancement in Engineering and Technology, 8(1), 03. https://doi.org/10.5281/zenodo.4003419

Power DMS. (2022). *Technology in the Fire Service*. https://www.powerdms.com/policy-learning-center/technology-in-the-fire-service

Ramasubramanian, S., Muthukumaraswamy, S. A., & Sasikala, A. (2020). Fire detection using artificial intelligence for fire-fighting robots. *2020 4th International Conference on Intelligent Computing and Control Systems (ICICCS)* (pp. 180-185). Madurai, India. https://doi.org/10.1109/iciccs48265.2020.9121017

Swati, A. D., Karishma, A. M., & Rashmi, A. (2020). Wireless firefighting robot. *International Journal For Research In Emerging Science and Technology*, *2*, 1-5.

Suguira, T., Hirata, Y., Yoshida, T., & Kusumoto, Y. (2018). Design of an autonomous robot for disaster response tasks in urban environments. *2018 IEEE International Conference on Robotics and Biomimetics (ROBIO)* (pp. 1201-1207). IEEE.

Surya, C., Revathi, V., A, S., & Suresh, K. (2019, November). Development of DTMF-centred remotely located fire extinguishing robot. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, 9, 39-43.

Wang, T., Cheng, C., & Ma, L. (2021). An autonomous rescue robot for disaster environments based on artificial intelligence. *Applied Sciences*, *11*(1), 347.

Zheng, W., Wang, C., Cai, Z., & Xue, Y. (2019). Rescue robot for earthquake disaster response. *2018 IEEE International Symposium on Robotics and Intelligent Sensors (IRIS)* (pp. 147-152). IEEE.