

Solar Powered Autonomous Fire Fighting Robot with Ammonium Ball Suppression Technology

**Vinodhini S.¹, Sidharth V.², Nishanth Niruban M.³,
Hariharan B.⁴, Harish Kumar M.⁵**

¹Assistant Professor, ^{2,3,4,5}Students, Department of Information Technology, Velammal Engineering College, India.

E-mail: ¹vinodhini@velammal.edu.in, ²rajsidharth010@gmail.com, ³mnishanthniruban08@gmail.com, ⁴bsangeetha359@gmail.com, ⁵harishkumar2005hk@gmail.com

Abstract

In this paper, a design, implementation, and experimental validation of a solar powered fire-fighting robot incorporating multisensor probabilistic fire detection, IoT remote monitoring capability, and ammoniabased fire-fighting mechanism is presented. For fire detection, the proposed framework employs inputs in terms of flame intensity, smoke density, and temperature changes processed through a logistic regression based probabilistic model. The process flow involved in this system includes environment sensing, processing of sensor data, probabilistic fire detection, autonomous movement towards fire origin, and releasing of suppression balls containing ammonia. A total of 120 tests are carried out under both fire and no fire environments for evaluation purposes. The experiments indicate that the system under test achieves accuracy in fire detection equal to 94.2%, having an average delay of 2.8 seconds while having a false alarm percentage of 5.8%. For power provision to the system, a 12V, 7AH rechargeable battery is employed with solar charging providing autonomy of operation up to 4.6 hours under no sun conditions. The experimental study proves that the multi-sensor system outperforms traditional approaches that depend on a single sensor or robotic system that operates under water when it comes to accuracy and reaction time. The multi-sensor system offers an intelligent and sustainable solution for fire detection.

Keywords: Solar Energy, Autonomous Fire-Fighting Robot, Ammonium Fire Suppression, IoT Monitoring, Smart Safety System, Renewable Robotics.

1. Introduction

Fire emergencies are amongst the highly damaging threats associated with industry plants, commercial establishments, residential premises, and forests. The rapid spreading of fire can result in serious damage not only to the infrastructure but also to the environment and even loss of lives. Conventional approaches to fire-fighting require substantial human involvement and put the rescuers at high risk of burns, inhalation of smoke, and structural collapse. Despite the use of conventional alarms for early warning of a fire threat, manual interventions may still lead to serious complications due to reaction time delay. Intelligent fire management systems using embedded systems and robotics along with the IoT are a new approach to fire emergencies due to advancements in technology. Intelligent fire management robots can detect the fire at its early stages, get to a dangerous location, and put off the fire with no human assistance.

Current fire-fighting robots use water suppression systems along with external power sources. In this case, water suppression may be ineffective in dealing with electrical and chemical fires and could damage machinery. Moreover, a power outage poses risks as robots operate depending on the availability of electricity. To overcome such issues, this study introduces Solar Powered Autonomous Fire-Fighting Robot coupled with Ammonium-Based Fire Suppression Ball Technology and Internet of Things (IoT). This innovation makes use of sustainable solar power and applies multi-sensor fusion technology including flame, smoke and temperature sensors for fire detection. Upon detection of fire, the robot will automatically move towards the source while avoiding any obstacles and employ suppression balls with ammonium to put out the flames. IoT will help to monitor the environment continuously and alert remote operators via cloud computing technology. Therefore, renewable energy consumption, intelligent decision-making, automatic navigation and fire suppression are among the most significant aspects of the proposed innovation. It could offer a more reliable and sustainable approach to fire-fighting and improve emergency response. The workflow of the proposed system consists of five stages: environmental sensing, sensor data preprocessing, probabilistic fire detection using logistic regression, autonomous navigation toward the fire location, and deployment of the ammonium suppression ball.

2. Related Work

Research on intelligent fire detection and robotic fire suppression has seen an increase with the development of embedded systems, wireless communication, and sustainable energy. The earlier research work was mainly focused on manually controlled or semi-autonomous fire-fighting robots for indoor applications. Kumar and Reddy (2017) designed a simple fire detection robot using flame sensors and a water pump system. While their design showed the capability to suppress fire, it lacked autonomous control and remote monitoring functions. Later, Sharma and Patel (2018) developed an IoT-based fire monitoring system that sent real-time notifications through cloud services. Their contribution was significant in improving the early warning system but was restricted to stationary sensor nodes and did not use autonomous fire suppression robots. Likewise, Zhang et al. (2019) designed a fire detection model using a wireless sensor network that improved the response time but did not include autonomous fire suppression capabilities. Autonomous navigation has also been considered in robotic fire systems. Verma and Kulkarni (2020) combined ultrasonic sensors and obstacle avoidance algorithms to allow robots to navigate through cluttered spaces. But in essence, their design still depended heavily on conventional water sprayer technology that is not very effective in cases involving electrical and chemical fires. Lee & Kim (2021) have examined various fire suppression technologies used in robots and highlighted the significance of small-scale self-triggering fire suppression mechanisms.

3. Proposed Work

This suggested system is the Solar Powered Autonomous Fire-Fighting Robot using Fire Suppression Ball Technology with Ammonium. This technology aims at developing a robot system that will be highly efficient and intelligent in fighting fires without much human assistance. The system focuses on sustainability, real-time monitoring, autonomous navigation, and fast response suppression.

The key components of the proposed system are:

- Sensor Data Acquisition and Preprocessing
- Feature Extraction and Sensor Calibration
- Fire Detection Algorithm

- Autonomous Navigation Mechanism
- IoT Monitoring and Alert System
- System Deployment and Performance Evaluation

3.1 Sensor Data Collection and Preprocessing

Environmental sensing plays a crucial role in fire detection. The proposed robotic system employs a combination of sensors to obtain real-time data on the environmental conditions. The sensors used include flame sensors to detect infrared radiation, MQ-2 smoke sensors to detect the concentration of combustible gas, and temperature sensors such as DHT11 and LM35 to detect variations in environmental temperature. In addition, ultrasonic sensors are used to detect obstacles in the environment.

The sensor data is prone to noise from environmental factors such as humidity, dust particles, and electrical currents. As such, preprocessing is carried out to improve the accuracy of the data. Analog data is converted to digital data using analog-to-digital conversion, followed by filtering techniques such as moving average filtering to eliminate sudden changes. Threshold-based preprocessing is used to differentiate between normal environmental changes and actual fire occurrences. For instance, normal temperature changes due to sunlight are distinguished from sudden temperature changes due to fire. In addition, temporary smoke particles are distinguished from high-density smoke emissions.

The sensor data is grouped into two operational states:

- Normal Environmental Condition
- Fire Alert Condition

3.1.1 Sensor Sampling Frequency and Accuracy

All environmental sensors operate at a sampling frequency of 5 Hz (five readings per second), which was experimentally determined to provide sufficient responsiveness while maintaining energy efficiency. The technical specifications of the sensors used in the prototype are summarized below:

- Flame Sensor: Infrared-based detection up to 100 cm, $\pm 5\%$ sensitivity variation

- MQ-2 Smoke Sensor: $\pm 5\%$ gas concentration variation
- LM35 Temperature Sensor: $\pm 0.5^\circ\text{C}$ accuracy
- DHT11 Temperature Sensor: $\pm 2^\circ\text{C}$ accuracy
- Ultrasonic Sensor (HC-SR04): ± 3 mm distance accuracy

Table 1. Sensor Specifications of the System

Sensor	Function	Range	Range (Duplicate)	Accuracy
Flame Sensor	Detects infrared radiation from flames	0–100 cm	0–100 cm	$\pm 5\%$
MQ-2 Smoke Sensor	Detects smoke and combustible gases	300–10000 ppm	300–10000 ppm	$\pm 5\%$
LM35 Temperature Sensor	Measures environmental temperature	-55°C to 150°C	-55°C to 150°C	$\pm 0.5^\circ\text{C}$
DHT11 Sensor	Temperature & humidity measurement	$0-50^\circ\text{C}$	$0-50^\circ\text{C}$	$\pm 2^\circ\text{C}$
HC-SR04 Ultrasonic Sensor	Distance measurement for obstacle detection	2–400 cm	2–400 cm	± 3 mm

Above Table 1 shows the technical specification of the sensors employed in the proposed robotic system.

3.2 Feature Selection and Sensor Optimization

The process of feature selection is crucial in improving the performance of the system in detecting fire. Given that there are different types of sensors whose readings are available simultaneously, it is necessary to identify those variables that affect the process of detection.

The main features considered in this research work are:

- Flame intensity level
- Smoke density concentration

- Rate of temperature rise
- Distance to obstacle
- Battery voltage level

The correlation is made in order to find out the relation between the temperature and smoke density while the fire happens. The correlation between the variables indicates an increased confidence level about the fire probability. Unrelated factors are removed to avoid unnecessary computational work as such factors have low or no correlation at all. Min-Max is utilized in order to normalize input sensor data:

$$X' = \frac{X - X_{\min}}{X_{\max} - X_{\min}}$$

Where

- X - is the current sensor reading
- X_{min} – is the minimum sensor value recorded
- X_{max} - is the maximum sensor value recorded

This normalization will help in making sure that all sensor data falls within a certain set standard range, thus providing better stability in probabilistic decision modeling within the system. Calibrating the sensors is also carried out at the beginning stage as a way of addressing any deviations from the normal environmental conditions. In order to determine the association between environmental factors during fire accidents, a correlation study was conducted between flames, smoke, and temperature. There existed a very high positive correlation between smoke and temperature increase, which means that they all play an important role in the process of detecting fires. Following Table 2 presents the correlation relationship between sensor parameters during fire conditions.

Table 2. Correlation Analysis Between Sensor Parameters

Parameter 1	Parameter 2	Correlation Coefficient
Smoke Density	Temperature Rise	0.82
Flame Intensity	Temperature Rise	0.76

Flame Intensity	Smoke Density	0.79
-----------------	---------------	------

3.3 Fire Detection Model

The fire detection system used in the proposal involves the probabilistic-based decision-making procedure that considers several environmental parameters before concluding whether a fire exists. In other words, rather than making decisions based on one sensor trigger, a combination of flame intensity, smoke density and the increase in temperatures are used to ensure that decisions made are highly accurate and minimize the occurrence of false alarms. Detection of fire starts by establishing the linear combination of the features under consideration. Weighting coefficients are then assigned to the different sensors based on their relevance. For example, the weighting coefficient will be high when it comes to flame intensity and the increase in temperature, while the coefficient will be low in case of minor changes in the levels of smoke density. An intercept term will be included in the linear combination equation to cater for the base levels in the environment.

Probabilistic outputs represent probabilities of fire occurring within the current environmental state. If the probability obtained is higher than the preset threshold, the system determines that there is a fire incident. In contrast, if the probability is lower than the threshold value, the system assumes that the environmental state is normal. The parameters of the model are optimized based on the experiments carried out, which include different fire and non-fire events. The weights can be varied so that the probability output of the model is highly accurate and avoids false alarms due to other phenomena in the environment, such as the presence of dust, smoke, or temperature changes. The training data used comprised a total of 120 records. There were 60 records of fire events and 60 records of non-fire events. The classification threshold was set at 0.5 as logistic regression produces probabilistic outputs ranging from 0 to 1. Thus, the probability of 0.5 equally divides the two categories.

3.3.1 Algorithm Mathematical Model

$$P(\text{fire}) = 1 / (1 + e^{-(\alpha_0 + \alpha_1 F + \alpha_2 S + \alpha_3 T)})$$

Where

- F = Flame intensity
- S = Smoke concentration

- T = Temperature rise
- α_0 = intercept coefficient
- $\alpha_1, \alpha_2, \alpha_3$ = weighting parameters

If $P(\text{fire}) > 0.5$, the system classifies the condition as fire and activates the robot navigation and suppression mechanism.

3.3.2 Algorithm 1: Fire Detection Procedure

Step 1: Read sensor values (flame, smoke, temperature)

Step 2: Normalize sensor values using Min-Max scaling

Step 3: Compute weighted sum using logistic regression

Step 4: Apply sigmoid function to compute probability

Step 5: If probability > 0.5

Fire detected

Activate robot navigation

Deploy suppression ball

Else

Continue monitoring

3.4 Autonomous Navigation and Suppression Mechanism

The suppression ball consisting of ammonium is fixed on a holder which is servo-driven and installed at the front end of the robot. As the robot gets close to the source of fire, the microcontroller sends instructions to drive the servo-motor and rotate the holder by about 90 degrees, thereby releasing the suppression ball close to the site of fire. Upon exposure to heat, the ball bursts and releases fire-extinguishing chemicals.

3.5 System Training, Testing and Evaluation

This robotic system is then tested and analyzed through experiments which seek to determine the level of reliability, efficiency, and effectiveness of the detection and fire-fighting capacity of the robot. This testing process occurs in an experimental setting which replicates the indoor fire environment and where various types of fires are induced in order to evaluate the system's performance. A number of experimental scenarios that are employed during the evaluation include the small flame ignition, smoke disturbance without the presence of actual fire, a slow rise in temperature due to external heating, as well as a simultaneous presence of both smoke and flame disturbances. These various experimental scenarios will enable the determination of the overall robustness of the system as well as its ability to detect fires despite other environmental disturbances. A systematic approach will be adopted when performing the tests by dividing the collected data into two parts namely training and testing phases. The first stage involves tuning of the system's parameters.

System performance measures include:

- Accuracy of Detection – It indicates the accuracy of the system in detecting fire.
- Response Time – Time taken from detecting fire to initiating robot movement.
- Suppression Time – Time taken from verifying the presence of fire to deploying the ammonium balls.
- False Alarm Rate– Number of times the fire alarm sounds when there is no actual fire.
- Battery Duration – Duration for which the system operates with stored solar energy.

The accuracy of fire detection can be measured by employing the following classification evaluation measure:

$$\text{Accuracy} = (\text{True Positives} + \text{True Negatives}) / \text{Total Observations}$$

Where:

- True Positives indicate the number of fire incidents correctly detected.
- True Negatives indicate the number of non-fire incidents correctly detected.

- Total Observations refer to the total number of test cases run during the experiment.

This provides a comprehensive measure of the system's ability to differentiate between fires and non-fires.

Response time is another criterion for measuring effectiveness together with accuracy, where timestamp logging is done by the microcontroller unit. Response time should be short so that one can get a clear picture of how the system responds in actual time and emergency conditions. The activation time of the suppression mechanism was analyzed to make sure that the system activates the ammonium-based fire suppression system in the best possible way to prevent the spread of fire.

3.6 Implementation and IoT Integration

The design of the autonomous fire-fighting robotic system includes an embedded microcontroller system such as Arduino Uno and ESP32. Microcontrollers are used as the brains behind the robotic system that controls the acquisition of sensor data, detection of fire, control of motors and actuator and activation of fire suppression system. Considering the various microcontrollers, the ESP32 microcontroller will be selected for implementation due to its Wi-Fi module, high speed and low power consumption capabilities. The microcontroller will be interfaced with all the environmental sensors including the flame sensor, MQ2 sensor for smoke, DHT11/ LM35 for temperature measurement, and ultrasonic sensors. The microcontroller reads the data acquired from the sensors at regular intervals and analyzes the data to make decisions. If the fire probability surpasses the threshold limit, then the microcontroller will control the motor driver modules in navigation and activation of fire suppression system using ammonium when the robot reaches the threshold distance. The Wi-Fi module in the ESP32 is also used to establish connectivity with the local network and transmit data to the cloud IoT platform. The data can be transmitted through periodic HTTP or MQTT protocol.

3.7 Expected Outcomes and Insights

The Solar Powered Autonomous Fire-Fighting Robot proposed in the project is anticipated to show a high level of reliability, responsiveness, and sustainability in real-life fire events. The use of multi-sensor data fusion, probabilistic fire detection decision making, autonomous robot navigation, and ammonium-based fire extinguishing techniques is expected

to contribute to efficiency as an alternative solution for the existing fire-fighting mechanism. One of the primary advantages of the proposed robot fire detection technique is related to its ability to analyze multiple parameters (i.e., intensity of the flame, density of smoke, and rise of temperature). In comparison to fire detectors based on one type of sensors, the proposed approach is expected to reduce the possibility of false alarms. The stable operation of the probabilistic fire detection algorithm under changing environment conditions will be an additional advantage of the proposed system.

3.7.1 Hardware Architecture and Circuit Design

Hardware architecture of the proposed solar-powered autonomous fire-fighting robot will help to efficiently detect and perform suppression of fires. Hardware architecture is based on four major hardware blocks: sensing unit, control unit, actuation unit, and power management unit. The sensing unit involves flame sensors, smoke sensors (MQ-2), and temperature sensors (DHT11/LM35) which sense the surroundings continuously. Sensors are interfaced with the microcontroller through analog and digital input pins. Signal conditioning circuits have been used to filter noise and stabilize sensor signals. Control unit comprises the ESP32 microcontroller which acts as the primary processing unit. Microcontroller will take care of signal processing, fire detection algorithm execution, and motor movements/suppression initiation. Control unit communicates with the motor driver circuit board (L298N) in order to control the movements of DC motors. Actuation units comprise two DC motors which will be responsible for driving the movement of the robot.

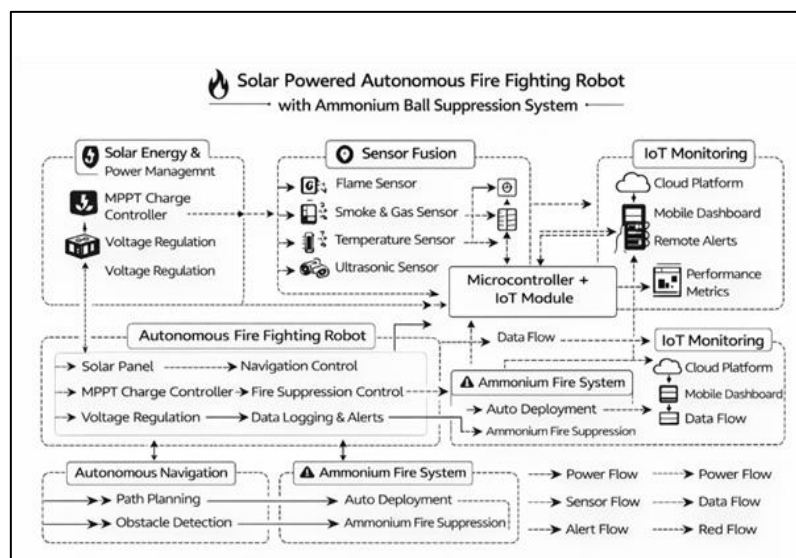


Figure 1. Shows the Hardware Architecture of the Proposed System

3.7.2 Energy Management and Power Optimization

Another aspect of the fire-fighting robot is the issue of energy efficiency, especially since the robot depends entirely on solar energy, which is considered renewable. The system uses some sophisticated power management techniques for its continuous operation and battery usage. Solar energy charges the rechargeable battery continuously when there is daylight available. A charge controller prevents the battery from being overcharged and deeply discharged, thereby prolonging the battery's life. During the absence of light, the robot shifts to battery power supply without interfering with the system functions. Energy optimization is performed on both hardware and software levels. The system's ESP32 microcontroller operates in a low-energy mode if no fire is detected, therefore saving energy. Polling is used on sensors rather than their continuous running. Battery performance is constantly checked and voltage levels regulated to prevent any system instabilities. In case the battery voltage is low below the critical level, non-essential operations are suspended without hindering fire detection functions.

Proper utilization of energy allows the system to remain active for a long time, making it suitable for remote industrial sites, warehouses, and smart buildings requiring constant monitoring for security purposes. The proposed robotic system utilizes a 12V 7Ah rechargeable battery with support from a solar energy charger. It was found that the robot could continue its operations uninterrupted for about 4.6 hours without any solar energy supply, but solar power increases the operational time substantially during the daytime.

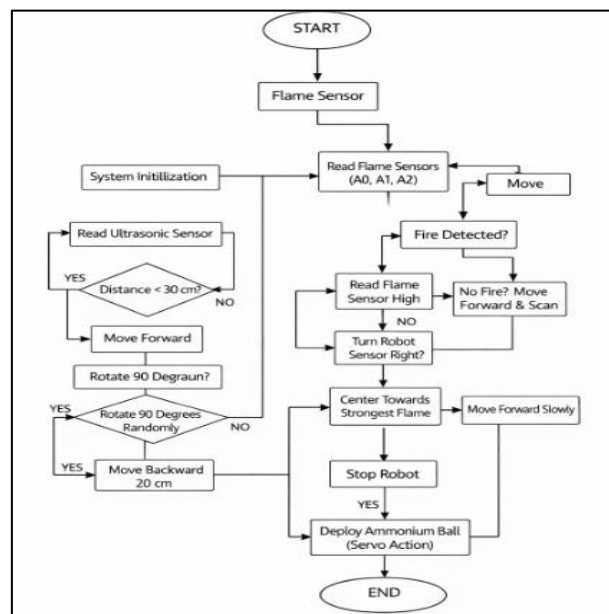


Figure 2. Illustrates the Operational Workflow

4. Results and Discussion

4.1 Experimental Setup

Experimental verification of the system under consideration took place in an indoor environment. Flame sources were created with the help of candle ignition to mimic fires. Smoke interference sources were created with the help of incense sticks without any flame to create situations of false alarms. Variation in temperature tests was performed through heating sources. The robotic unit was initially located 2 meters away from the flame source. The sensors kept tracking environmental variables such as flame strength, smoke concentration, and variation in temperature. The robotic unit moved towards the fire location once the probability of detection was more than the threshold value.

4.2 System Performance

The classification performance of the suggested fire detection model has proved to be very efficient during the experiment. The system was tested in different fire and non-fire cases, and the outcomes have provided confirmation that the suggested model can be implemented in real-life practice. As the detection process involves binary classification, either fire or normal environment, a probabilistic approach based on logistic regression was used for the detection process. In the proposed model, the probability of fire occurrence is determined using the logistic sigmoid function, where the probability of fire is given by one divided by one plus the exponential of the negative weighted sum of sensor inputs.

Table 3. Experimental Performance Results

Parameter	Value
Total experiments	120
Fire cases	60
Non-fire cases	60
Detection accuracy	94.2%
False alarm rate	5.8%
Response time	2.8 seconds

Suppression activation time	3.5 seconds
Battery endurance	4.6 hours

Table 3 presents the experimental performance results obtained during system evaluation.

The proposed fire detection system was evaluated using 120 experimental observations consisting of 60 fire scenarios and 60 non-fire scenarios. The multi-sensor probabilistic detection model demonstrated a detection accuracy of 94.2%. On average, the robot activated in 2.8 seconds after the start of fire detection, while the process of suppressing it took 3.5 seconds. As for the false alarm rate, it accounted for 5.8% only, which is much lower than in case of fire detection with one sensor.

4.3 Output Screenshots

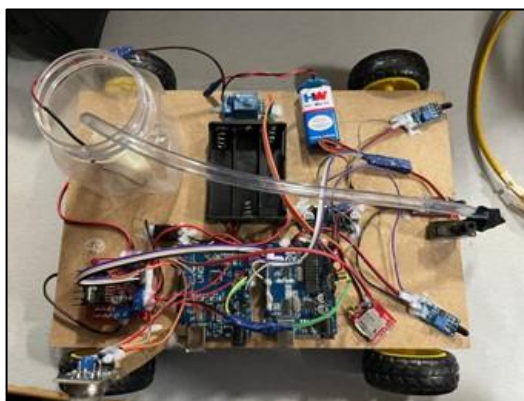


Figure 3. Presents the Front View of the Developed Prototype

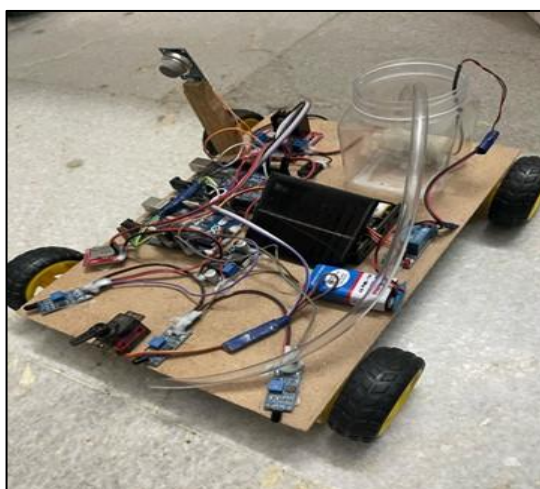


Figure 4. Side View Configuration

The experimental results show that the developed algorithm can detect fire efficiently without any high percentage of false alarms. Using a multi-sensor probabilistic algorithm helps improve the detection accuracy because it performs faster than other techniques such as the single sensor techniques.

Table 4. Comparison of Fire Detection Methods

Method	Sensors Used	Detection Accuracy	False Alarm Rate	Response Time
Flame Sensor Only	Flame	82.3%	14.5%	3.5 s
Smoke Sensor Only	MQ-2	85.7%	11.2%	3.2 s
Temperature Only	LM35	78.6%	16.3%	3.8 s
Proposed Multi-Sensor Model	Flame + Smoke + Temp	94.2%	5.8%	2.8 s

It is evident from Table 4 that the multi-sensor approach outperforms the single-sensor approach in terms of fire detection accuracy.

4.4 Future Enhancements

Further improvements to the suggested fire-fighting robotic system will incorporate the use of highly sophisticated artificial intelligence and techniques for real-time data fusion of the environment. Even though the suggested robotic system is based on probabilistic modeling using multiple sensors, deep learning techniques like CNN and RNN can also be used to analyze the pattern of the fires. The inclusion of vision-based fire detection capabilities using thermal imaging or camera modules can greatly enhance early-stage flame detection capabilities. Computer vision algorithms can assist in distinguishing actual fire, light reflections, and non-hazardous heat sources, thus minimizing false positives. Real-time environmental data such as humidity levels, airflow conditions, and material properties of the surrounding environment can also be included in the fire detection algorithm. Dynamic adjustment of sensor thresholds based on environmental conditions can thus enhance fire detection capabilities. For instance, in high-temperature industrial settings, automatic recalibration of baseline sensor thresholds can prevent unnecessary alarms. Advanced navigation enhancements such as Simultaneous Localization and Mapping (SLAM) can enable

efficient robotic operation in complex indoor settings. GPS integration may also enable the system to be used for outdoor fire monitoring applications such as forest fire prevention.

4.4 Unique Contribution of the Work

Summary of key contributions of this study:

- Creation of a solar energy driven automatic fire-fighting robot.
- Use of a multiple sensor probabilistic model of fire detection with logistic regression.
- Incorporation of ammonia fire suppression balls for efficient fire suppression.
- Use of Internet of Things for real-time monitoring of fires.
- Experimental verification with 120 fire and non-fire data samples.

Showing of high efficiency of the developed technique in terms of fire detection accuracy (94.2%) with reduced false alarm rate relative to classical approaches.

5. Conclusion

The research has discussed the design, implementation, and testing of an autonomously moving fire-fighting robot powered by solar energy using multi-sensors for detection based on probability theory and ammonium salt-based extinguishing. The detection accuracy of the system is 94.2%, while the response time is 2.8 seconds. Renewable energy source and Internet of Things (IoT) are added for sustainable operation and remote monitoring. Further improvement in the future may include vision detection and SLAM-based robot navigation using AI techniques.

References

- [1] Ding, Weili, Tao Yang, Jingxiao Li, Changchun Hua, and Dianrui Mu. "A Real-Time Flame Detection and Situation Assessment Algorithm for Firefighting Robots: A Real-Time Flame Detection and Situation Assessment Algorithm..." *Fire Technology* 61, no. 4 (2025): 2571-2591.

- [2] Yang, Tao, Weili Ding, Yaohui Wang, Taiyu Chen, and Dianrui Mu. "Real-time flame detection and localization for firefighting robots." *Robotics and Autonomous Systems* (2025): 105147.
- [3] L. Guruprasad, M. U. Yashwanth, P. V. Prasad, B. V. Shreevara, and Gangappa, "Autonomous Fire Fighting Robot", *IJRESM*, vol. 3, no. 7, pp. 393–396, Jul. 2020, Accessed: Apr. 06, 2026. [Online]. Available: <https://journal.ijresm.com/index.php/ijresm/article/view/106>.
- [4] Jadhav, S. S., S. S. Bhosale, V. G. Shelar, P. B. Patil, and S. S. Jamadar. "Fire Fighter Robot Using IOT and Mobile Application." *International Journal of Research In Science & Engineering* 46 (2024): 49-57.
- [5] Vivek Kumar, Satyam Kumar Mishra, Kashif Murtaza, Mohd. Sawood, Amit Kumar, Fire-fighting robot using Arduino: A Fire Detection and Suppression System. (2025). *International Journal of Research in Advanced Science and Engineering Technology*. <https://doi.org/10.22214/ijraset.2025.72413>
- [6] Hemalatha G., Abinaya G. P., Dharneesh B., Rakshitha D., Sivachalapathy V., Uma Maheshwari S. Warehouse Fire-Fighting Rover (2025). *International Journal of Research in Advanced Science and Engineering Technology*. <https://doi.org/10.22214/ijraset.2025.70540>
- [7] Qiu, Yundan, Wei Wang, Junpeng Zhan, and Yanmei Huang. "Research on Automatic Flame Recognition and Tracking of Intelligent Fire Robot Based on STC89C52." *Academic Journal of Engineering and Technology Science* 6, no. 8 (2023): 54-60.
- [8] Sucuoglu, Hilmi Saygin. "Development of Real-Time Fire Detection Robotic System with Hybrid-Cascade Machine Learning Detection Structure." *Processes* 13, no. 6 (2025): 1712.
- [9] Chairman M, Priyatharsini S, Bhuvaneshwari M, Nandhakumar C, Gopinath S, "Autonomous Fire-Fighting Robot for Detection and Prevention" (2024). *International Research Journal of Multidisciplinary Scope*, 5(3), 969–976. <https://doi.org/10.47857/irjms.2024.v05i03.0922>

- [10] Yahaya, Izyan. "Autonomous safety mechanism for building: Fire fighter robot with localized fire extinguisher." *International Journal Of Integrated Engineering* 12, no. 1 (2020): 304-314.
- [11] Jindal, Kshitij, Anthony Wang, Dinesh Thakur, Alex Zhou, Vojtech Spurny, Viktor Walter, George Broughton, Tomas Krajnik, Martin Saska, and Giuseppe Loianno. "Design and deployment of an autonomous unmanned ground vehicle for urban firefighting scenarios." *Field Robotics* 1 (2021): 1-17.
- [12] Deng, Rong, Saizhe Ding, Yifei Ding, Meng Wang, Xinyan Huang, and Asif Sohail Usmani. "Autonomous navigation of non-perception firefighting robot through CCTV-informed vision sharing." *Expert Systems with Applications* 296 (2026): 129210.
- [13] Ayala, Angel, Bruno Fernandes, Francisco Cruz, David Macêdo, Adriano LI Oliveira, and Cleber Zanchettin. "KutralNet: A portable deep learning model for fire recognition." In *2020 International Joint Conference on Neural Networks (IJCNN)*, pp. 1-8. IEEE, 2020.
- [14] Yang, Tao, Weili Ding, and Junjie Luo. "Fire SLAM: a visual Simultaneous Localization and Mapping algorithm for firefighting robots." *Robotica* (2025): 1-17.
- [15] Alwan, O. H., Alshekhly, M. N. A., Al-Aloosi, R. A., Fakhri, O. F., Aljibori, H. S. S., & Abdullah, O. I. (2024). Systematic development of an autonomous robotic car for fire-fighting based on the interactive design approach. *EUREKA: Physics and Engineering*, (3), 61-72. <https://doi.org/10.21303/2461-4262.2024.003326>
- [16] Sarthak Dharmik, Pankaj Rawat, Suryakant Singh, Gitesh Wankhede, F. B. Sayyad, "Fire Extinguisher Robot Using Multiple Flame Sensors and Arduino" (2022). *International Journal of Research in Advanced Science and Engineering Technology*. <https://doi.org/10.22214/ijraset.2022.43320>
- [17] Amol A. Bhosle, Shardul S. Bodhe, Sakshi U. Bodhe, Madhura M. Birajdar, Sharvari V. Bodas, "Fire Fighting Robot Prototype with Gas and Flame Sensors" (2022). *International Journal of Research in Advanced Science and Engineering Technology*. <https://doi.org/10.22214/ijraset.2022.48012>

- [18] SUNIL, R. KEWATE, and CHAUDHARI CR. "Prototype of Fire Fighting Robot." INTERNATIONAL JOURNAL 11, no. 6 (2024): 936-942.
- [19] Rosengreen, C. (2026, February 16). AI-Powered Robot Vehicles Team Up to Fight Fires. Griffith News. <https://news.griffith.edu.au/2026/02/16/ai-powered-robot-vehicles-team-up-to-fight-fires/>.
- [20] Agrawal, Ujjwal. "Role of uav-iot networks in future wildfire detection." In Machine learning and Internet of Things in fire ecology, pp. 273-300. IGI Global Scientific Publishing, 2025.