© AUG 2026 | IRE Journals | Volume 10 Issue 2 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV10I2-1722672

Autonomous Fire-Fighting Robotic Vehicle Using Arduino

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Abstract- Fire incidents in industrial, laboratory and restricted environments can expose firefighters to extreme temperature, toxic gases, explosions and structural hazards. This work presents the design and implementation of a compact autonomous fire-fighting robotic vehicle based on an Arduino Uno controller. The prototype integrates infrared flame sensors, geared DC motors, a motor driver, a servo-controlled water nozzle, a water pump, a lithium-ion battery and a microcontroller-based decision algorithm. The robot continuously monitors the fire-sensor outputs, determines the direction of the detected flame, moves toward the source and activates a water-spraying mechanism. The nozzle is swept by a servo motor to increase the effective coverage of the extinguishing stream. The original prototype dissertation demonstrates the complete hardware, software and control sequence, including forward, backward, left, right and stop functions. The present paper reformulates that work as a research article and identifies the experimental parameters that should be reported for publication-quality validation. The approach is intended as a low-cost platform for initial fire response in controlled indoor environments, rather than as a replacement for certified industrial firefighting equipment.

Keywords—fire-fighting robot, Arduino Uno, flame sensor, autonomous navigation, water pump, servo motor, fire detection, robotics.

I. INTRODUCTION

Fire is a rapidly developing hazard capable of causing injury, loss of life and extensive property damage. The risk becomes particularly serious when the incident occurs in locations containing combustible materials, toxic substances, pressurized systems or unstable structures. Human firefighters may be unable to approach such locations safely. Robotic systems can therefore provide a useful first-response or support capability by entering restricted areas, locating a flame and performing an initial suppression action while keeping personnel at a safer distance.

The submitted project, entitled "Fire Fighting Robotic Vehicle Using Arduino," was developed as a B.Sc. Physics dissertation at K. S. Rangasamy College of Arts and Science during December 2024–May 2025. The source document describes a mobile vehicle using an Arduino Uno, flame sensors, motors, a motor driver, a servo motor, a water pump and a lithium-ion battery. It also provides the embedded control program and a prototype-oriented conclusion. □filecite□turn0file0□L9-L17□

Recent publications show that Arduino-based firefighting robots remain an active area of low-cost robotics research. For example, a 2022 study reported an Arduino Uno robot using three flame sensors, gear motors, a motor driver, a pump and a servo-controlled water ejector. A 2025 laboratory-oriented study reported an Arduino-based platform with a 180° infrared flame-detection unit, autonomous movement and servo-controlled spraying. These works indicate that the basic architecture is feasible, but also highlight the need for quantitative validation and a clearly defined contribution. [1], [2]

The objective of this paper is therefore to present the existing prototype as a structured research contribution, describe its sensing and control architecture, document the implementation, and define a reproducible experimental framework for evaluating fire-detection and extinguishing performance.

II. RELATED WORK

Earlier firefighting robots have used combinations of flame or thermal sensors, autonomous navigation, pumps and directional spray mechanisms. The literature reviewed in the original dissertation includes intelligent firefighting tank robots, embedded firefighting robots and sensor-based security/fire systems. filecite turn0file0 L27-L31

Recent work has moved toward improved sensing, autonomy and vision. A 2025 paper on an Arduino-based laboratory firefighting robot reported 95.8% flame-detection accuracy, a maximum reported extinguishing distance of 90 cm, an average extinguishing time of 18.9 s and a 98.0% success rate over 250 tests. These values are from that published study and must not be presented as measurements of the present prototype. [1]

Another 2025 study described a prototype firefighting robot using Arduino control, flame sensing, obstacle detection and automatic water spraying. A separate 2025 study proposed real-time flame detection and 3-D localization for firefighting robots, illustrating the trend toward camera/vision-based localization rather than simple threshold-based flame sensing. [3], [4]

The literature suggests a research gap for low-cost platforms that clearly quantify the relationship between sensor threshold, approach distance, nozzle sweep, response time and extinguishing success. The present prototype provides a useful hardware baseline for such an evaluation.

III. SYSTEM DESIGN AND METHODOLOGY

3.1 System Architecture

The proposed vehicle consists of a sensing subsystem, control subsystem, locomotion subsystem and extinguishing subsystem. The Arduino Uno functions as the central controller. Three directional infrared flame-sensor channels are represented in the program as right, front and left inputs. The controller interprets the sensor readings and selects the appropriate movement or suppression action. The original project lists Arduino Uno, flame sensor, servo motor, motor driver, motors, lithium-ion battery and water pump as the principal hardware requirements. filecite turn0file0 L35-L37

Subsystem	Main component	Function
Controller	Arduino Uno / ATmega328P	Reads sensors and executes control logic
Fire sensing	Three IR flame-sensor channels	Detects flame direction
Locomotion	DC geared motors + motor driver	Forward, reverse and turning motion
Extinguishing	12 V-class pump + water tank	Delivers extinguishing water
Nozzle positioning	Servo motor	Sweeps water stream toward flame
Power	Lithium-ion battery	Portable power source

3.2 Fire Detection and Decision Logic

The controller samples the three flame-sensor channels and compares them with programmed thresholds. When the right, front or left channel indicates a flame, the robot stops and activates the pump while sweeping the nozzle through a predefined angular range. When the measured signal lies within the programmed approach region, the robot moves in the corresponding direction. If no valid fire condition is present, the vehicle stops. The source code implements these actions using conditional branches and dedicated functions for forward, backward, right-turn, left-turn and stop. ・filecite・turn0file0・L89-L97・

Because the prototype relies on sensor thresholds, these thresholds should be experimentally calibrated under the intended lighting conditions. Bright ambient infrared radiation, reflections and flame size can affect sensor response. Therefore, the final paper should report the calibration procedure, threshold values, test distance and false-positive/false-negative counts.

3.3 Navigation and Extinguishing Mechanism

Two geared DC motors provide vehicle movement. The motor-driver interface allows the controller to reverse motor polarity and therefore generate forward, backward and turning motions. When a

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DOI: https://doi.org/10.64388/IREV10I2-1722672

flame is detected, the robot changes from navigation mode to suppression mode. The pump is activated and the servo sweeps the nozzle across a specified angular interval. The original program contains separate sweep sequences for the right, front and left flame conditions. ・filecite・turn0file0・L89-L96・

IV. HARDWARE IMPLEMENTATION

4.1 Arduino Controller

The Arduino Uno used in the project is based on the ATmega328P and provides digital and analog I/O suitable for interfacing with the sensors, motor driver, servo and pump-control circuitry. The source dissertation describes the controller architecture and identifies the Uno as the central control element. ・filecite・turn0file0・L37-L41・

4.2 Flame Sensor

The prototype uses infrared flame sensors to identify the presence and direction of a flame. Three channels are used in the control program: right (ir_R), front (ir_F) and left (ir_L). The directional arrangement permits the controller to make a simple steering decision before activating suppression. ・filecite・turn0file0・L85-L89・

4.3 Motor Driver and Drive Motors

The project describes an L293D-class motor-driver interface and geared DC motors for vehicle movement. The motor driver acts as the power interface between the low-power controller outputs and the motors. The source document also contains the forward, reverse and turning routines used by the control program. ・filecite・turn0file0・L55-L59・

Editorial note for the final submission: the dissertation contains references to both L293D and L298/L298N-style pin labels. The exact motor-driver IC used in the physical prototype should be verified from the hardware and photographs before journal submission, and the schematic, bill of materials and program should be made consistent.

4.4 Pump and Servo-Controlled Nozzle

A water pump supplies the extinguishing stream, while the servo motor positions the nozzle. The original project specifies a water tank and pump and uses servo-pulse control to sweep the nozzle. ・filecite・turn0file0・L61-L65・

V. SOFTWARE AND CONTROL ALGORITHM

The control program is implemented for the Arduino platform. At startup, the sensor pins, motor-driver pins, servo and pump outputs are configured. The controller then continuously reads the three flame-sensor channels. The source code uses threshold conditions to select between suppression, forward motion, reverse motion and turning. ・filecite・turn0file0・L85-L93・

Algorithm:
Initialize sensor, motor, servo and pump interfaces.
Read right, front and left flame-sensor values.

If a flame is detected strongly in a direction, stop the vehicle, activate the pump and sweep the nozzle.

If the sensor indicates an approach condition, move toward the flame.

If the directional signal indicates the fire is off-axis, reverse or turn toward the stronger indication.

If no valid fire condition is present, stop the vehicle and keep the pump off.

Repeat the sensing and decision cycle continuously.

VI. EXPERIMENTAL VALIDATION

The original dissertation demonstrates the prototype and gives the control program and qualitative conclusion, but it does not provide a complete quantitative results table for detection accuracy, response time, extinguishing time, water consumption, battery endurance or repeated-trial success rate. ・filecite・turn0file0・L99-L101・

Therefore, these values must be measured before the manuscript is submitted as a fully validated research article.

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Parameter	Test method	Required result	Present manuscript
Detection accuracy	Repeat flame/no-flame trials at fixed distances	TP, TN, FP, FN and % accuracy	To be measured
Detection distance	Increase flame distance until reliable detection fails	Maximum reliable distance (cm)	To be measured
Response time	Time from detection threshold crossing to pump activation	Mean ± SD (s)	To be measured
Extinguishing time	Time from pump activation to visible flame extinction	Mean ± SD (s)	To be measured
Success rate	Repeated extinguishing trials	Successful trials / total trials	To be measured
Water consumption	Measure tank mass/volume before and after each trial	mL per successful suppression	To be measured
Battery endurance	Continuous operation under defined load	Operating time (min/h)	To be measured
Obstacle performance	Repeated obstacle-course trials	Collision-free rate / completion time	To be measured

For a strong journal version, at least 20–30 repeated trials per principal operating condition are recommended, with mean, standard deviation and confidence intervals reported where appropriate. Testing should be performed with controlled flame size, known distances, fixed ambient-light conditions and a documented safety procedure. No claim of fire-safety certification should be made from small laboratory flames alone.

VII. RESULTS AND DISCUSSION

Based on the source project, the prototype successfully implements the intended sequence of flame sensing, directional movement, pump activation and servo-controlled water spraying at the prototype level. The program contains explicit routines for movement and suppression, demonstrating that the system is capable of autonomous decision-making rather than requiring continuous manual motor commands. ・filecite・turn0file0・L89-L97・

However, publication-quality discussion requires numerical evidence. In particular, the effect of flame distance and sensor orientation on detection reliability should be quantified. The extinguishing mechanism should also be evaluated against flame size and initial distance. A useful performance metric is suppression success rate, defined as the number of successful extinguishing trials divided by the total number of valid trials.

The proposed system should be positioned as a low-cost prototype for controlled indoor initial-response scenarios. It is not appropriate to claim suitability for large industrial fires without thermal protection, certified suppression equipment, robust navigation, communications and extensive field testing. Recent research is increasingly incorporating vision, IoT monitoring and more advanced localization, which provides clear directions for future development. [3], [4], [5]

VIII. COMPARISON WITH RECENT WORK

Study	Controller / sensing	Suppression	Reported validation	Main focus
Present prototype	Arduino + 3 IR flame channels	Water pump + servo nozzle	Quantitative data to be added	Low-cost autonomous prototype
Adilshah et al., 2022 [2]	Arduino + 3 flame sensors	Water sprinkler	Prototype description	Autonomous detection/suppression
Maruf et al.,	Arduino + 180° IR	Servo-	95.8% accuracy; 18.9 s	Laboratory firefighting

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2025 [1]	unit	controlled water	mean extinguishing time; 98% success	
Yang et al., 2025 [4]	Real-time vision/localization	Firefighting robot platform	Real-world flame localization study	3-D flame localization
Kaur et al., 2025 [3]	Microcontroller + IR detection	Targeted water spraying	89% detection; 85% suppression success	Low-cost indoor system

The comparison shows that the principal opportunity for the present work is not simply to repeat an Arduino-plus-flame-sensor architecture, since similar systems have already been reported. The publishable contribution should instead come from rigorous calibration, quantitative performance characterization, a clearly documented control strategy, and—if the authors add it—an experimentally demonstrated improvement such as adaptive sensor thresholds, improved nozzle control, obstacle avoidance, IoT telemetry or vision-assisted fire localization.

IX. LIMITATIONS AND FUTURE WORK

The prototype has several limitations. Infrared flame sensing can be affected by ambient radiation and line-of-sight conditions. The small water reservoir limits the duration of suppression. The mobile platform is intended for controlled surfaces and does not establish performance on debris, stairs or high-temperature industrial environments. The source project itself proposes future additions including a larger water/CO2 carrying capability, improved battery capacity, stronger pumping, more sensitive sensors, GSM/eSIM communication, GPS and image processing. ・filecite・turn0file0・L101-L101・

A next-generation version should integrate a thermal or vision sensor with the flame detector, log sensor data and timestamps, implement adaptive thresholds, add obstacle mapping, provide remote emergency monitoring and include a fail-safe mechanism that prevents water discharge when a person is detected in the suppression zone. Vision-based localization and IoT monitoring are consistent with current research directions. [4], [5]

X. CONCLUSION

This paper presents a reformulated research-article version of an Arduino-based autonomous fire-fighting robotic vehicle. The system combines directional flame sensing, autonomous motor control and a servo-positioned water-spraying mechanism. The original prototype demonstrates the complete sensing-to-suppression control sequence and provides a practical low-cost platform for controlled fire-response experiments. ・filecite・turn0file0・L99-L101・

To make the work suitable for a strong peer-reviewed publication, the next essential step is experimental validation rather than additional descriptive hardware text. Detection accuracy, response time, extinguishing time, success rate, operating range, water consumption and battery endurance should be measured under controlled and repeatable conditions. Once those data are inserted, the manuscript can be finalized for a suitable robotics, embedded-systems or safety-engineering conference/journal.

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