OPEN ACCESS
Global Journal of Research in Engineering & Computer Sciences
ISSN: 2583-2727 (Online)
Volume 04 | Issue 02 | March-April | 2024
Journal homepage: https://gjrpublication.com/gjrecs/
Review Article

Design and Construction of a Low-cost Autonomous Firefighting Robot

[1]Muhammad Auwal Shehu,[1]Muhammad Baballe Ahmad*,[2]Auwal Salisu Yunusa,[3]Danladi King Garba,[4]Hari Maghfiroh

[1] Department of Mechatronic Engineering, Nigerian Defence Academy (NDA), Kaduna, Nigeria
[2] Department of Mechatronic Engineering Technology, Kano State Polytechnic, Kano, Nigeria
[3] Department of Mechanical Engineering, Nigerian Defence Academy (NDA), Kaduna, Nigeria
[4] Department of Electrical Engineering, Universitas Sebelas Maret (UNS), Surakarta, Indonesia

DOI: 10.5281/zenodo.10845943 **Submission Date:** 05 Feb. 2024 | **Published Date:** 21 March 2024

***Corresponding author:** Muhammad Baballe Ahmad
Department of Mechatronic Engineering, Nigerian Defence Academy (NDA), Kaduna, Nigeria
ORCID: 0000-0001-9441-7023

Abstract
This paper focuses on the design and construction of a mechatronic system for indoor firefighting. The objective was to create a machine that could identify and extinguish small fires in closed spaces. With the help of infrared flame sensors, the robot detects the fires and autonomously navigates to the fire location and safely sprays it with water. In order to facilitate the work of firefighters and minimize the number of casualties, we develop an automated system for the early detection and extinguishment of fires. Simulation results in proteus and practical experiments were conducted to verify the effectiveness of proposed robotic system. The experiment results showed that the robot was able to detect fires in three different directions, viz., forward, left, and right directions; and was able to rapidly put off the fires, effectively.

Keywords: Autonomous robots, Mobile robots, Firefighting robots, Embedded systems.

Introduction
Fire incident is a disaster that can potentially cause loss of life, damage to property and injury to the affected victim. Fire fighters are primarily tasked to handle fire incidents, but they are often exposed to higher risks when extinguishing fire, especially in hazardous environments such as in nuclear power plant, petroleum refineries and gas tanks. They are also faced with other difficulties, particularly if fire occurs in narrow and restricted places. Unpredictably, fires can spread quickly, consuming entire buildings in a matter of seconds. Prompt actions are essential in these kinds of emergency scenarios. Conventional firefighting techniques frequently depend on human intervention and results in untimely response and difficulties. Thus, a robot can be employed to address these problems. Robots are designed to remove human factor from labour intensive or dangerous work and also to act in inaccessible environment. With the invention of such a devices, lives and properties can be saved.

A recent trend that has become popular is to use robots instead of humans to handle fire hazards. This is mainly because they can be used in situations that are too dangerous for any individual to involve themselves in. There are several existing types of robots for firefighting at home. Autonomous indoor firefighting robot are designed to detect for indoor fires, navigate to a suitable proximity of the fire and extinguish it. The robot processes information from its sensor and hardware components. Ultraviolet, infrared and visible light are used to detect the components of the environment. The main and only work is to deploy the robot in a fire prone area and the robot will automatically work once it detects a fire breakout.

The rest of the paper is ordered as follows. In section two, a brief survey of the related studies is presented. The third section is devoted to the robot's hardware and software. Results are discussed in section four. Lastly, section five concludes the paper.

Related studies

Many authors have proposed different techniques for firefighting. Cutting-edge sensors and algorithms are employed by intelligent fire recognition systems for rapid and precise detection of fires [1]. A fire incident at the industry poses a serious risk to human life and would result in significant losses. Early fire detection and modest firefighting efforts could prevent significant losses and save lives. To carry out early firefighting action, the paper [2] suggested integrating the autonomous firefighting mobile robot into Internet of Things (IoT) system. In the event that a fire is discovered, the IoT system notifies the fire safety division and launches a mobile robot into action. Using a path-planning algorithm, a firefighting robot arrives at a fire location, engages in firefighting operations, and transmits the video feed of the fire location to the control room [3]. In addition to alerting the fire safety officers, early action prevents the fire from spreading. By watching the video that the firefighting robot sent, fire safety officers can better prepare for handling the fire incident in the interim.

In [4] a small crawler robot was designed using the virtual prototype technology, taking into account the unique working environments and safety of firefighters in homes and other fire scenes. The firefighting robot's general design scheme was suggested, and a stand-alone suspension system with effective shock absorption was created. The development of an explosion-proof waterproof shell for a specialized robot allows for precise temperature and unsafe object detection at the fire scene through the robot's vision and temperature identification [5,6]. Research shows that the small crawler fire-fighting robot has high detection intelligence and structural reliability, which is of great significance to the fire-fighting operations [1]. Businesses with a high risk of fire incidents could combine their current fire alerting system with a mobile robot that fights fires [3]. A robotic system called the Arduino-based Fire Fighting Robot with SMS Alert System is made specifically to detect and put out indoor fires. The robot looks for signs of fire using flame sensors. When a fire is detected, the user can receive alerts via SMS messages from the robot thanks to its GSM module. This makes it possible to respond quickly in order to reduce damage and save lives. The robot is made up of an Arduino board, sensors, motor drivers, and a GSM module. With the extra advantage of remote communication and control, the Arduino-based Fire Fighting Robot with SMS Alert offers a dependable and effective solution for fire detection and suppression overall [7,8].

Elsewhere, another project used Arduino technology to create an autonomous firefighting robot that could locate and put out fires [9]. Humanoid robot applications are the subject of active research in an attempt to increase productivity, security, efficacy, and quality of work while lowering the number of firefighter fatalities and injuries [10]. The robot can improve the fire's quality, productivity, safety, and efficiency. It is smaller and more pliable than other robots. Furthermore, the robot's small size and automatic control make it suitable for use in hazardous environments like tunnels or nuclear power plants where fires occur in tight spaces. This developed autonomous system shows off its ability to automatically locate fires and put them out with water that has been stored in a container on it [11]. The development of an autonomous, human-free firefighting robot that can identify and put out fires is the main topic of this report. It is crucial that we have a system in place to handle a dangerous incident like this because fires can break out in our homes, workplaces, factories, or labs at any time. The systems that are currently on the market are smoke detectors, which are effective but have certain drawbacks. For example, they cannot detect small fires and the water showers do not provide enough coverage to completely put out a fire. Additionally, the smoke detectors fail to alert people to the location or status of the fire, which can cause long-term harm because it delays help. Other related works focussed on using ultrasonic sensors [12,13], light detection and ranging (LiDAR), and infrared sensors to help robots navigate through complex and dynamic environments. With the aid of light-dependent resistors (LDRs), a line-follower robot [14] can track and navigate through a maze of lines, avoiding obstacles, and put out any indoor fires.

Our objective was to create a robotic system that could identify small fires in a closed space. After detecting the fire with the help of infrared flame sensors, the robot autonomously approaches the fire and safely sprays it with water. In order to facilitate the work of firefighters and minimize the number of casualties, we develop an automated system for the early detection and extinguishment of fires.

Design and Development

A. Hardware Design and Construction

The block diagram of the project implementation is as depicted in Figure 1. The robot is made up of an Arduino UNO board, L298N motor driver to control two motors, two IR flame sensors, a relay for activating a water pump, a buzzer for fire alarm and a 12V rechargeable DC source. A three-wheel mobile robot chassis houses all the hardware units and also provides mobility for the robot.

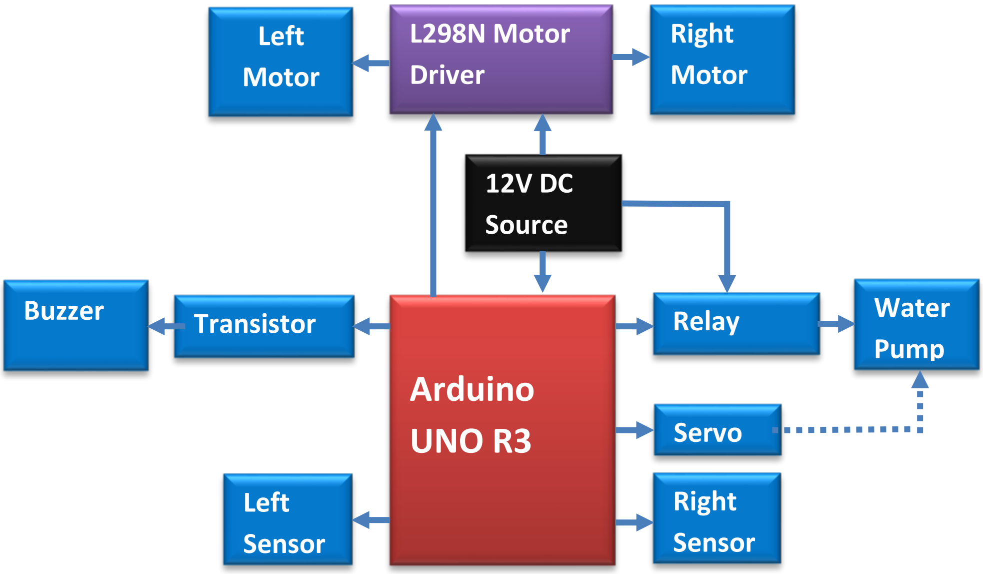

Figure 1: Hardware block diagram

Similarly, the complete circuit diagram for the firefighting robot is as shown in Figure 2 below. As it can be seen from the circuit, at the heart of the robotic system is an Arduino microcontroller board. The Arduino UNO acts as the brain of the whole control circuitry. The robot consists of the two sensors that are interfaced in the control circuitry. Sensors are used to detect fire prone area all directions and moves the robot towards fire location. When the robot reaches fire zone then a pump extinguisher is attached on the robot comes into action to extinguish the fire. The major hardware components used in the firefighting robot project are summarized in Table I.

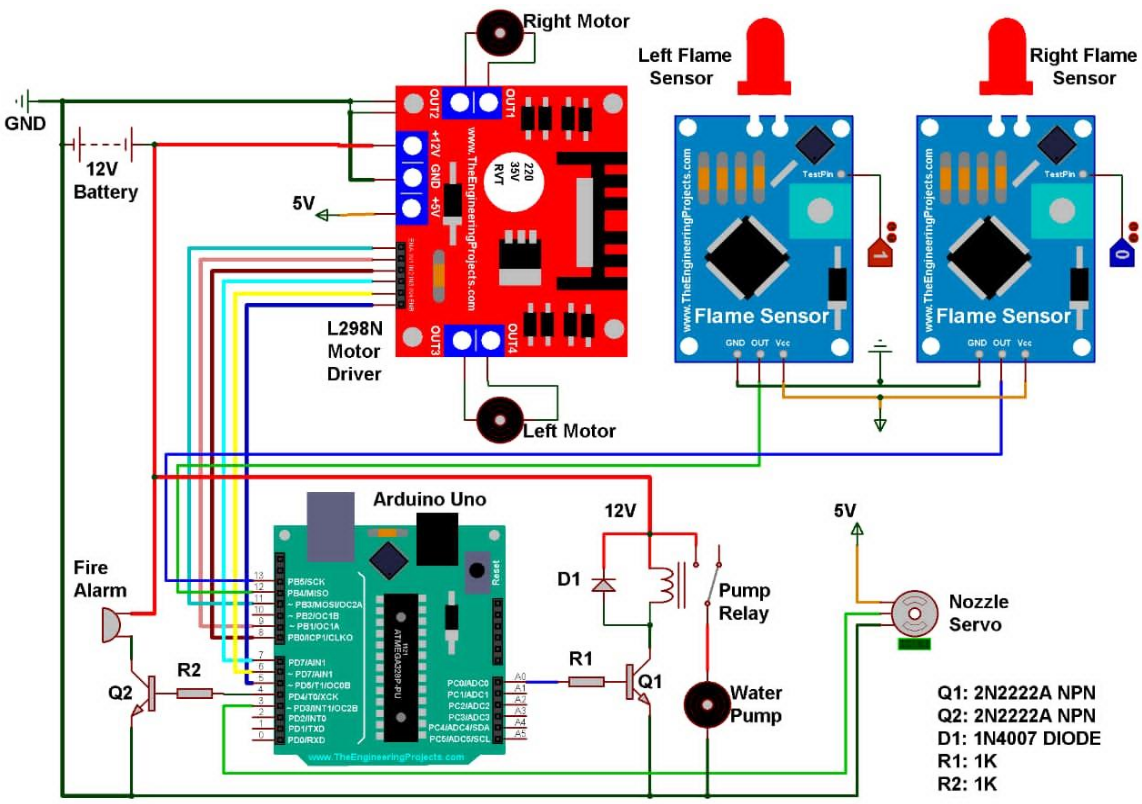

Figure 2: The firefighting robot's complete circuit diagram

Table I: List of components for the hardware implementation

S/N	Component	Quantity
1	Arduino UNO R3	1
2	Mobile Robot Base	1
3	Geared DC Motors with PVC Wheels	2
4	IR Flame Sensors	2
5	Buzzer	1
6	5VDC Relay Breakout	1
7	2N2222A Transistor	1
8	Micro Servo Motor	1
9	Front Wheel	1
10	Switch	1
11	L298N Motor Driver	1
12	12V DC water Pump	1
13	Jumper Wires Assortment	-
14	18650 Lithium-ion Batteries	3
15	Water Container	1
16	Small Hose	1
17	Water Nozzle	1
18	1KΩ Resistors	1
19	Miscellaneous	-

B. Software Design and Development

The programming of the firefighting robot's software is as depicted Figure 3 which is based on a monolithic approach. The robot reads the flame sensors digital outputs to check whether a flame is detected. When a fire is detected in any direction, the micro-controller processes these instructions and then instructs the vehicle motors to run the robot in desired direction. When the robot is in a close proximity of the fire, it stops at a safe distance (determined by the IR sensor reading returned by the ADC). Next, the water is sprayed on the fire by activating the DC pump and turning the servo motor from 0 to 180 and vice versa until the fire is put off.

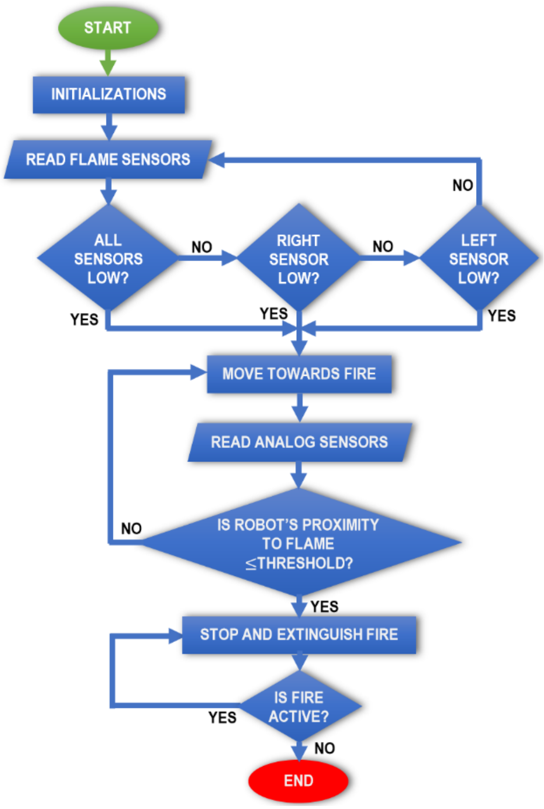

Figure 3: The robot's program flowchart

The software for the robot was developed in Arduino IDE based on the C++ language. We will proceed to explain the major sections of the program code. In the following code excerpt, the servo library is invoked followed by some declarations:

```
#include <Servo.h>
#define servoPIN 3
#define LMspeed 11
#define RMspeed 5
#define LM1 9
#define LM2 8
#define RM1 7
#define RM2 6
#define RIRdigital 13
#define LIRdigital 12
#define RIRanalog A2
#define LIRanalog A1
#define dispen A0
#define Buzzer 4
```

Next, threshold values for analogue flame sensor readings are defined as integers and stored in respective variables:

```
int LeftThreshold=80;
int RightThreshold=85;
```

Subsequently, a servo object was created with the name “ourServo”:

```
Servo  ourServo;
```

Next, inside the run-once setup () function the Arduino pins are configured followed by motors speed setups and servo motor initializations:

```
void setup () {
   pinMode(LM1,OUTPUT);
   pinMode(LM2,OUTPUT);
   pinMode(RM1,OUTPUT);
   pinMode(RM2,OUTPUT);
   pinMode(LMspeed,OUTPUT);
   pinMode(RMspeed,OUTPUT);

   pinMode(dispen,OUTPUT);
   pinMode(Buzzer,OUTPUT);

   pinMode(servoPIN,OUTPUT);

   pinMode(RIRdigital,INPUT);
   pinMode(LIRdigital,INPUT);

   pinMode(RIRanalog,INPUT);
   pinMode(LIRanalog,INPUT);

   analogWrite(LMspeed, 125);
   analogWrite(RMspeed, 140);

   ourServo.attach(servoPIN);
   ourServo.write(90);

   digitalWrite(dispen, HIGH);}
```

At this juncture, the body of the loop () function is defined. The content of the loop () function include: sensors scanning, conditional statements, motors state control functions, and fire extinguishing function:

```
void loop (){
   if (digitalRead(RIRdigital)==0 &&
      digitalRead(LIRdigital)==0){
```

```
          digitalWrite(Buzzer,HIGH);
          Forward ();
    if(analogRead(RIRanalog)<=RightThreshold ||
       analogRead(LIRanalog)<=LeftThreshold){
        Stop ();
        extinguish_fire(); }}

  else if (digitalRead(RIRdigital) ==1 &&
          digitalRead(LIRdigital)==0) {
          digitalWrite(Buzzer,HIGH);
          SlowLeft(); }

  else if (digitalRead(RIRdigital) ==0 &&
          digitalRead(LIRdigital)==1) {
          digitalWrite(Buzzer,HIGH);
          SlowRight();}

  Else {
    Stop ();
    digitalWrite(Buzzer,LOW);
    digitalWrite(dispen,HIGH);
    ourServo.write(90);}}

void Forward () {
  digitalWrite(LM1, HIGH);
  digitalWrite(LM2, LOW);
  digitalWrite(RM1, HIGH);
  digitalWrite(RM2, LOW);}

void SlowRight(){
  digitalWrite(LM1, HIGH);
  digitalWrite(LM2, LOW);
  digitalWrite(RM1, LOW);
  digitalWrite(RM2, LOW);}

void SlowLeft(){
  digitalWrite(LM1, LOW);
  digitalWrite(LM2, LOW);
  digitalWrite(RM1, HIGH);
  digitalWrite(RM2, LOW);}

void Stop(){
  digitalWrite(LM1, LOW);
  digitalWrite(LM2, LOW);
  digitalWrite(RM1, LOW);
  digitalWrite(RM2, LOW);}

void extinguish_fire(){
  Stop ();
  digitalWrite(dispen, LOW);

  for (int j = 1; j <= 2;j++) {
    ourServo.write(75);
    delay(600);
    ourServo.write(110);
    delay(600); }

  ourServo.write(90);
  digitalWrite(dispen,HIGH);
  digitalWrite(Buzzer,LOW); }
```

Results and Discussion

The program was written in the Arduino integrated development environment (IDE) and compiled into a machine code (binary file). With the help of the IDE's upload functionality, this machine was flashed into the Arduino board's ATMega328P microcontroller. The Arduino Uno controller on the robot's chassis is responsible for both the robot's navigation in the direction of the fire, its fire detection and fire extinguishing ability. The water pump on board the robotic vehicle is servo-controlled. With the help of the dual H-bridge module used to drive the robot's two-rear motors, two motors are interfaced to the microcontroller to move the vehicle, and a front wheel is used to position the robot. The robot body is equipped with a water tank and water pump, which are controlled by the microcontroller output. The microcontroller is interfaced with a motor driver integrated circuit (IC), which allows the controller to drive the motors. On the robot chassis, two infrared flame sensors are fixed to detect fire and travel to the site to extinguish the fire.

The final robot prototype is shown in Figure 4. Before the actual hardware implementation, simulation results were obtained and found to be working in Proteus software. Sequel to the success recorded in the simulation phase, the robot's performance was further investigated from a practical perspective using candle fire to simulate a real fire scenario. It was found that the firefighting robot can successfully detect the fire source and completely extinguish it in real-time. After detecting the fire with the help of infrared flame sensors, it approached the fire and extinguished it from a safe distance determined by the threshold readings from the flame sensor's analogue signals.

Figure 4: The firefighting robot prototype in operation

Conclusion and Recommendations

In this work, a robotic system has been designed and developed and the functionality of the system was verified using a simulation environment and practical experiments. From the experimental results, the robot can sense smokes and fire accurately in a short time. The achieved objective was creating a robotic system that was able to identify small fires in a closed space, autonomously navigate the source of fire and extinguish it.

References

1. S. Bari, et al., "Forest Fires: Challenges and Impacts", Global Journal of Research in Engineering & Computer Sciences, vol. 2, no. 4, pp. 19-23, 2022.

2. P. D. V. Prasad, et al., "Vision Based Fire Fighting Robot using IoT", International Journal of Engineering Technology and Management Sciences, vol. 6, no. 4, 2022.
3. Kashif Altaf, Aisha Akbar, Bilal Ijaz; "Design and Construction of an Autonomous Fire Fighting Robot", 2007 International Conference on Information and Emerging Technologies, Karachi, Pakistan, 2007, pp. 1-5.
4. K.L. Su, "Automatic Fire Detection System Using Adaptive Fusion Algorithm for Fire Fighting Robot", Systems, Man, and Cybernetics, IEEE International Conference, 8-11 October 2006, pp. 966-971.
5. M. A. Baballe, M. I. Bello, "A Study on the Impact and Challenges of Temperature Detection System", Global Journal of Research in Engineering & Computer Sciences, vol. 1, no. 2, pp. 22-26, 2021.
6. M. A. Baballe, M.A. Shehu, A. Surajo, D.Z. Yanmida, & A. Muhaimin, "Robots for Fighting Fires: A Comparative Analysis", Global Journal of Research in Engineering & Computer Sciences, vol. 3, no. 6, pp. 57–61, 2023.
7. A Verma, et al., "Design and Construction of Automatic Fire Fighting Robot with SMS Notification", Advanced Production and Industrial Engineering, pp. 1-8, 2022.
8. S. O. OWOEYE, et al., "Development of A Fire Extinguishing Robot with SMS Alert Feature", Proceedings of the 3rd International Conference on Engineering Innovations as a Catalyst for Rapid Economic Growth (COLENG 2021), Federal University of Agriculture, Abeokuta, Nigeria, May 24 -26, 2021.
9. Aryan Verma, Naman Yadav, Harshita Chaubey, Aditya Srivastava, Ajay Sharma, "Arduino Based Firefighting Robot with SMS Alert," Journal of Emerging Technologies and Innovative Research (JETIR), 2023.
10. Wu et al., "Design and Development of Intelligent Fire-fighting Robot Based on STM32", Journal of Physics: Conference Series, 1748, 2021.
11. Raju, S. S. Mohammed, J. V. Paul, G. A. John and D. S. Nair, "Development and implementation of Arduino microcontroller based dual mode fire extinguishing robot," IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal, 2017.
12. Tushar Nandkishor Satbhai, R.M.K., Anant Vijay Patil, Manish Patil, "Fire Fighting Robot", International Journal on Recent and Innovation Trends in Computing and Communication (IJRITCC), 2016.
13. B. R. V. Prasad, et al., "Artificial Intelligence in an Autonomous Fire Fighting Robot", International Research Journal of Modernization in Engineering Technology and Science, vol. 05, no. 04, 2023.
14. M.A. Baballe, A. I. Adamu, Abdulkadir S. B., & Amina I, "Principle Operation of a Line Follower Robot", Global Journal of Research in Engineering & Computer Sciences, vol. 3, no. 3, pp. 6–10, 2023.

CITATION

MA Shehu, MA Baballe, AS Yunusa, DK.Garba, & H. Maghfiroh. (2024). Design and Construction of a Low-cost Autonomous Firefighting Robot. In Global Journal of Research in Engineering & Computer Sciences (Vol. 4, Number 2, pp. 35–42). https://doi.org/10.5281/zenodo.10845943