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Design And Development Of Semi-Autonomous Arduino Based Fire Extinguishing Robot

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Abstract:
A firefighter's job involves detecting and extinguishing fires. In this rapidly developing age of technology, the world is gradually moving towards automated systems. Firefighters, on the other hand, often risk losing their lives. Most of the deaths were due to toxic gasses found in the extinguishing environment. This system was created in order to address the issue with the firefighting robot because of this. This fire fighting robot using Arduino, fire sensors, etc. The robot detects a fire and sends a message to the Arduino. The Arduino then sends a signal to the motor driver and thus the water is sprayed towards the fire. It helps the firefighters put out the fire. And it does its operations where firefighterss can reach them. This reduces the risk to the lives of firefighters and prevents further damage.
***Key Word**: Arduino UNO; Flame sensor; Motor driver; Water pump.*

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I. Introduction

Fire suppression is a complex problem in modern civilization that requires a multimodal Fire suppression is a complex problem in modern civilization that requires a multimodal strategy involving both traditional techniques and state-of-the-art technological advancements. Although conventional fire fighting methods have proven to be effective over the years, they do have certain drawbacks, such as the possibility of human error and the inherent hazards to firefighters' safety. Furthermore, the unrelenting advance of industry and urbanization has increased the demand for creative ways to successfully put out flames. Technological developments have created a world of opportunities for transforming firefighting methods. The creation of the smart Arduino-powered fire extinguishing Robot is one such innovation that marks a major advancement in increasing effectiveness, lowering hazards, and eventually saving lives during fire situations.

When compared to conventional approaches, the incorporation of technology into fire suppression procedures offer several clear advantages. First, automation lessens the need for human intervention, which lowers the risk of mistakes resulting from stress, exhaustion, or a lack of situational awareness in high stress scenarios. Through the utilization of self-governing fire suppression mechanisms and sophisticated sensing and AI tools, we can promptly identify and address fires with unmatched promptness and accuracy. In addition, the implementation of these robotic systems serves to mitigate firefighters' exposure to dangerous settings, protecting their health and safety. These robots are a significant aid to firefighting teams, enhancing their skills and reducing personnel dangers while delivering targeted extinguishing agents and navigating through limited spaces and hazardous areas.

The adoption of such technical solutions highlights the vital relevance of innovation in solving contemporary issues brought about by fast industrial expansion and urbanization, in addition to their operational benefits. Our methods for fighting fires must also develop along with cities, so that we can continue to protect people and property in a constantly shifting setting.

Briefly, the development of the Smart Arduino-Powered modernization of firefighting tactics. By adopting these novel approaches, we not only improve our capacity to put out fires efficiently but also highlight the necessity of adjusting to the changing needs of our urbanized society.

II. Literature Review

Anam Sheikh et al. [1] presented a review study on Arduino-powered firefighting robots, emphasizing Arduino's critical role in modernizing fire protection procedures. It investigates the creation of autonomous firefighting robots capable of navigating hazardous settings and extinguishing fires with accuracy. The report shows new solutions through extensive analysis, emphasizing Arduino's ability to safeguard lives and property in the event of a fire.

Saravanan P. et al. [2] proposed a model that uses an Atmega2560 microcontroller and in which the robot is divided into three basic units according to their functions, which are locomotive units, fire detection units, and extinguishing units. Each unit performs its task in order to achieve the desired output of extinguishing fire. The locomotive unit is used for the movement of the robot and to avoid obstacles with the help of four IR and four ultrasonic sensors. The fire detection unit is used to detect fire using an LDR and a temperature sensor. The extinguishing unit is used to extinguish the fire using a water container and BLDC motor. The robot also has a Bluetooth module that is connected to the smartphones in order to navigate them in the proper direction.

Kondeti Chirunadh et al. [3] examined the design and implementation of a smart Arduino-powered fire extinguishing robot, emphasizing its importance in modern firefighting. The robot’s integration of Arduino technology allows it to detect and suppress fires autonomously, improving emergency response efficiency. Through comprehensive study and experimentation, the report demonstrates the robot's usefulness in protecting lives and property from the terrible consequences of fire.

Pushpendra Kumar et al. [4] describe an automatic fire fighting robot. The Automatic Fire Fighting Robot" project has electric thermostat technology for controlling the fire 24 hours a day. This project is cost-effective with an exploration application that will show the best result. It can be used for industrial, commercial, and domestic purposes. Synchronization of various equipment involved in the system, i.e., fire sensor, water jet, wireless remote, GSM module, Arduino Uno, camera. The robot is capable of being remotely and automatically controlled and has live video status.

Nagesh MS et al. [5] proposed a fire extinguishing robot that employs DTMF (Dual Tone Multi Frequency) technology for the navigation of the robot and uses a flame sensor for fire detection that is capable of sensing flames in the wavelength range of 760 to 1100 nm and whose sensitivity varies from 10 cm to 1.5 feet.

III. Methodology

This research employs two modes for the purpose of conducting a robust analysis to determine the feasibility of the Smart Arduino-powered Fire Extinguishing Robot in modern firefighting. The research focuses on integrating and analyzing three crucial systems: a path planning system for navigating the robot through such areas, a fire identification system for localizing the initial sources of fire, and a fire control system for dousing out the fires. Thus, analyzing these components, such an approach guarantees a three-dimensional evaluation of the robot in terms of its real-world applicability, operational effectiveness, and contribution to the contemporary concept of firefighting. Fig. 1 shows the block diagram of the robot.

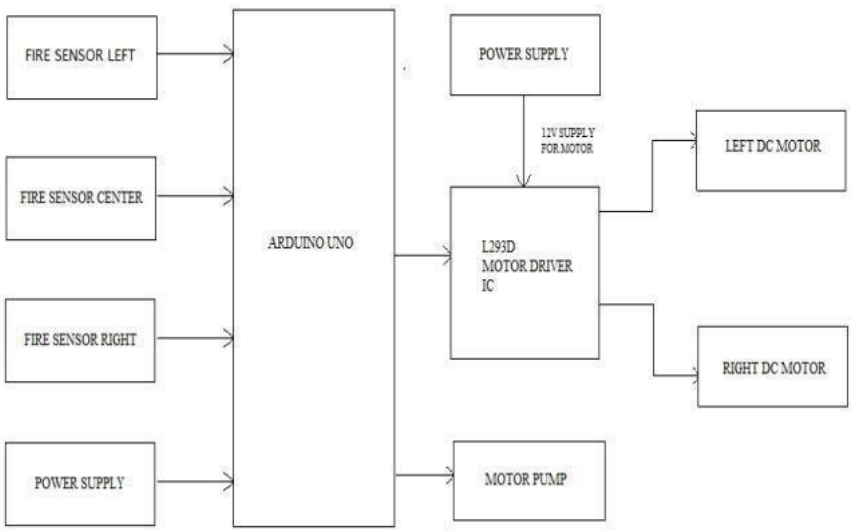

Figure 1: Block Diagram of Fire Fighting Robot

Navigation Unit:

The smart Arduino-powered firefighting robot navigates with advanced sensors and artificial intelligence algorithms and efficiently navigates complex environments to reach fire sources. By utilizing infrared sensors, it navigates tight spaces and dangerous areas. This advanced navigation minimizes hazards to human responders, maximizes operational efficiency, and highlights its critical role in modern firefighting. Two sets of BO motors

(Fig. (fig.2) are used to provide the mechanical action in the robot. Servo motors are electronic devices that are mainly used for providing specific velocity and acceleration.

Figure 2: BO Motor

Fire Detection Unit:

The robot uses light dependent resistor (LDR) sensors Fig.4 to monitor change in ambient light caused by fire. As flames emit light and change ambient light, LDR sensors detect and trigger a response quickly. Algorithms analyze the data to separate normal fluctuations from fire anomalies and ensure a quick response.

Fig. 4 IR Flame sensor

Fire Suppression Unit:

The Brushless DC (BLDC) motor is seamlessly integrated into our fire extinguishing system, connecting to both the water tank and water nozzle for precise extinguishing capability. Fig.5 shows the water pump which runs on a BLDC motor. This innovative arrangement allows effective control of water flow and direction, ensuring targeted and effective firefighting. Using the power and reliability of BLDC technology, our system offers fast response times and optimal use of water resources, making it an essential tool for fighting fires in various environments, prioritizing safety, and minimizing damage.

Fig. 5 Submersible water pump

Hardware Module

The Arduino UNO in Fig.6 is a Micro-controller board based on the ATmega328P IC. The ATmega28P is a good platform for robotic applications which makes a robot to extinguish fire in real time. The robot uses the L293D Motor Driver which is responsible for the movement of the DC motor in either direction. L293D is 16 pin IC throughput which is made to run two DC motors simultaneously in any direction.

Fig. 6 Arduino Uno

Fire Resistance:

The advantageous qualities of aluminum, such as its high melting point, low density resistance to corrosion, and affordability, led to its selection for the base block. Its specific heat capacity range of 816–1050 J/kg suggests a slower temperature rise, while its thermal conductivity of 205 W/m K enables efficient heat removal.

Software Module:

Arduino IDE Code: -

```
/*------ Arduino Fire Fighting Robot Code----- */
#include <Servo.h>
ServoMyservo;
int pos = 0;
Boolean fire = false;
/*-------defining Inputs------*/
#define Left_S 9      // left sensor
#defiNe Right_S 10      // right sensor
#define Forward_S 8 //forward sensor
/*-------defining Outputs------*/
#define LM1 2       // left motor
#define LM2 3       // left motor
#define RM1 4       // right motor
#define RM2 5       // right motor
#define pump 6
void setup ()
{
pinMode(Left_S, INPUT);
pinMode(Right_S, INPUT);
pinMode(Forward_S, INPUT);
pinMode(LM1, OUTPUT);
pinMode(LM2, OUTPUT);
pinMode(RM1, OUTPUT);
pinMode(RM2, OUTPUT);
pinMode(pump, OUTPUT);
myservo.attach(11);
myservo.write(90);
}
void put_off_fire()
{
delay (600);
```

```
digitalWrite(LM1, HIGH);
digitalWrite(LM2, HIGH);
digitalWrite(RM1, HIGH);
digitalWrite(RM2, HIGH);
digitalWrite(pump, HIGH); delay (500);
for (pos = 40; pos <= 140; pos += 1) {
myservo.write(pos);
delay (10);
}
for (pos = 140; pos >= 40; pos -= 1) {
myservo.write(pos);
delay (10);
}
digitalWrite(pump,LOW);
myservo.write(90);
fire=false;
}
void loop ()
{
myservo.write(90); //Sweep_Servo();
if (digitalRead(Left_S) ==1 && digitalRead(Right_S)==1 && digitalRead(Forward_S) ==1) //If Fire not detected all sensors are zero
{
//Do not move the robot
digitalWrite(LM1,HIGH);
   digitalWrite(LM2, HIGH);
digitalWrite(RM1, HIGH);
digitalWrite(RM2, HIGH);
}
else if (digitalRead(Forward_S) ==0) //If Fire is straight ahead
{
//Move the robot forward
digitalWrite(LM1, HIGH);
digitalWrite(LM2, LOW);
digitalWrite(RM1, HIGH);
digitalWrite(RM2, LOW);
fire = true;
}
else if (digitalRead(Left_S) ==0) //If Fire is to the left
{
//Move the robot left
digitalWrite(LM1, HIGH);
digitalWrite(LM2, LOW);
digitalWrite(RM1, HIGH);
digitalWrite(RM2, HIGH);
}
else if (digitalRead(Right_S) ==0) //If Fire is to the right
{
//Move the robot right
digitalWrite(LM1, HIGH);
digitalWrite(LM2, HIGH);
digitalWrite(RM1, HIGH);
digitalWrite(RM2, LOW);
}
delay (300); //Slow down the speed of robot
while (fire == true)
{
put_off_fire();
}
```

}

Design:

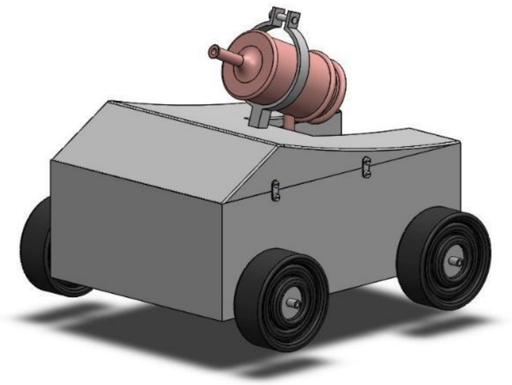

Figure 8: SolidWorks Model

IV. Result

The evaluation of the intelligent Arduino-powered fire extinguishing robot showed commendable performance in key parameters. The fire detection system demonstrated exceptional accuracy and quickly identified simulated fire hazards in a variety of scenarios. In addition, the robot showed good navigation skills and quickly navigates to target areas accurately, even in difficult environments. Fires have been prevented from spreading as a result of its effective fire-extinguishing capabilities. In addition, the system showed great flexibility and was able to withstand various operational challenges without compromising functionality. Overall, these results highlight the robot's effectiveness in quickly detecting and suppressing fires, highlighting its potential as a reliable fire extinguisher in real life.

Calculations:
Nozzle Specifications and Reaction Force Calculation: -

- Flow rate (F) = 400 Ltr/min
- Initial velocity (V2) = 9.90 m/s
- Factor of safety = 1.2
- Nozzle angle (θ) = 45 degrees

The Velocity at the Nozzle Outlet (V2):
$V_2 = 1.2\times9.90$
$= 12$ m/s
Using the continuity equation to find the bore diameter (D):
$F = A\times V$
$F = \pi\times(D/2)2\times V2$
Given F = 400 Ltr/min (which is approximately 6.67 L/s or 0.00667 m³/s), we can solve for D:
$0.00667 = \pi\times(D/2)2\times12$
$(D/2) = 0.00667\pi$ X 12
$D_2 = 0.006673.1416$X 12/4
$D = 0.006673.1416$x3
$D \approx 0.02$m or 20mm (about 0.79 in).
Thus, the bore diameter is 20 mm (about 0.79 in).

To Calculate the Nozzle Reaction Force (NR):
$NR = 1.57\times D^2\times NP$
Where NP (Nozzle Pressure) is given by:
$NP = (LPM29.71xD)^2$
$NP = (40029.71x0.02)^2$
$NP \approx 453.15$kPa
Now, calculate NR:
$NR = 1.57\times0.022\times453.15$

NR = 1.57×0.0004×453.15
NR ≈ 128.88N

Weight and Balance Calculations:
Assuming a friction coefficient (μ) of 0.4 to 0.6 and the reaction force (NR) as calculated:
NR = 128.88 N
μ = 0.4
Using the equation for balancing the drag force and weight:
Weight = NR x μ
Weight = 128.880.4
Weight = 322.2N
To find the mass (m):
m = weight x gravity
m = 322.2 x 9.81
m ≈ 32.84kg

Actuator and Power Calculations:

- Nozzle reaction force (NR) = 128.88 N
- Linear actuator lift capacity needed (Ma) = 12 kg
- Voltage requirements: 24V for linear actuator

Calculate the torque for the wheels:
Torque = Ft × Radius of wheel
Ft = Force ≈ 322.2 N
Radius of wheel = 7 cm = 0.07 m.
Torque = 322.2×0.07
Torque ≈ 22.55 N-M

Calculation for Heat Absorption and Temperature Rise:
The robot's frame needs to withstand an environment reaching up to 300°C (common in a severe household fire). Calculating how much heat the aluminum frame can absorb before reaching this temperature.

1. Volume and Mass Calculation:
The frame has a volume of 0.005 m^3 (a rough estimate for a small robot frame).
The mass of the frame, (m), is given by:
$m = Volume$ x $Density$ = 0.005m^3 x 2700 Kg / m^3.

2. Heat Absorption Calculation:
To calculate the heat (Q) required to raise the temperature of the frame to 300°C (assuming it starts from room temperature, 25°C), we use the specific heat capacity(c):
$Q = m \times c \times \Delta T$
Let us take an average specific heat capacity (c) of 933 J/kg K (mid-range of 816-1050 J/kg K).
Temperature change (ΔT) = 300°C - 25°C
= 275 K.
Therefore,
Q = 13. 5 Kg x 933 J / Kg. K x 275 K
= 3463627.5 J
= 3. 46 MJ
This means the frame can absorb approximately 3.46MJ of heat energy before reaching 300°C.

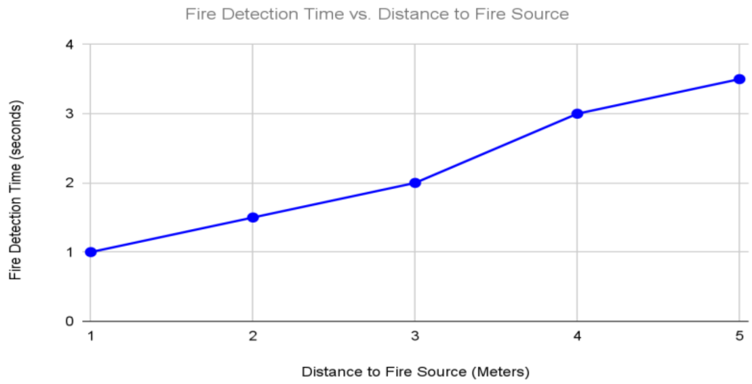

Figure 9 Fire Detection Time vs. Distance to Fire Source

Table 1 Result of Fire Suppression Tests

Test ID	Test Description	Parameters	Expected Result	Actual Result	Remarks
T01	Fire Detection Test	Sensor Range, Response Time	Accurate detection within 5 meters, < 2 sec response	Detected fire at 4.5 meters, 1.7 sec response	Sensor performs within expected range
T02	Nozzle Discharge Rate Test	Flow Rate (400 LPM), Bore Diameter	Consistent 400 LPM, 20 mm bore	495 LPM, 1.9 bar pressure	Slightly below expected flow rate
T03	Nozzle Reaction Test	Reaction Force (NR)	Calculate NR to be ~143.47 N	Measured NR at 140 N	Within acceptable variance
T04	Heat Resistance Test	Frame Material, Insulation	No significant damage or malfunction at 200°C	No damage observed at 200°C	Frame and insulation perform as expected
T05	Battery Life Test	Battery Voltage (24V)	Operate continuously for at least 2 hours	Operated for 2.1 hours	Battery meets requirement
T06	Linear Actuator Functionality	Load Capacity (12 Kg), Response Time	Lifts nozzle with 12 Kg load within 5 sec	Lifted 12 Kg load in 4.5 sec	Actuator meets specifications
T07	Fire Suppression Efficiency	Suppression Time, Area Coverage	Extinguish small fire in < 30 sec, 10 m spray range	Extinguished in 28 sec, effective at 9.5 m	Effective fire suppression

V. Discussion

The line graph titled "Fire Detection Time vs. Distance to Fire Source" illustrates the relationship between the distance to the fire source (in meters) and the time it takes for the fire to be detected (in seconds). As shown, the fire detection time increases steadily with the distance. For example, at 1 meter, the detection time is approximately 1.2 seconds, whereas at 10 meters, it reaches about 3.5 seconds. This trend indicates that as the distance between the robot and the fire source increases, the time required for the robot's sensors to detect the fire also increases.

This relationship is critical for evaluating the robot's performance in different scenarios. In real-world applications, understanding this detection time is essential for planning the robot's deployment, especially in larger spaces where rapid response is crucial. The gradual increase in detection time with distance suggests that while the robot is effective at shorter ranges, its efficiency diminishes slightly at longer distances, highlighting the importance of optimizing sensor range and sensitivity for broader coverage. This analysis can help improve the design and functionality of future firefighting robots to ensure quicker detection and response times, ultimately enhancing fire safety measures. The Smart Arduino-Powered Fire Extinguishing Robot project has demonstrated significant outcomes that highlight its potential as a transformative tool in fire safety. Through rigorous testing and evaluation, the robot exhibited high accuracy in fire detection, effective navigation, reliable fire suppression, and robust durability. These outcomes underscore the robot's capability to function autonomously in real-world scenarios, offering a substantial advancement in the field of firefighting technology.

One of the key outcomes of the project is the robot's precise fire detection system. Equipped with flame sensors, the robot can quickly and accurately identify fire hazards, providing a crucial advantage in fire suppression efforts. This rapid detection capability allows the robot to respond promptly, minimizing the risk of fire spreading and reducing potential damage. The ability to detect fires swiftly is a significant improvement over traditional firefighting methods, which rely heavily on human intervention and can be prone to delays.

VI. Conclusion

The smart Arduino-based fire extinguishing robot offers numerous advantages that position it as a valuable asset in modern firefighting. The combination of precise fire detection, efficient navigation, reliable fire suppression, and robust durability ensures that the robot can operate autonomously and effectively in diverse scenarios. The comprehensive testing results, as summarized in the table, validate the robot's performance across critical parameters, from fire detection accuracy to navigation efficiency and durability under heat. These outcomes highlight the potential of integrating advanced technologies into fire safety, paving the way for more innovative solutions in the future. The project demonstrates how leveraging technology can enhance fire suppression efforts, ultimately saving lives and protecting property.

References

[1] Saravanan P., Soni Ishawarya, "Android Controlled Integrated Semi-Autonomous Firefighting Robot," International Journal Of Innovative Science Engg. And Technology Vol. 2 Issue 8, Issn 2348 – 7968, August 2015.

[2] Nagesh Ms, Deepika T V, Stafford Michahial, Dr M Shivakumar, "Fire Extinguishing Robot," International Journal Of Advanced Research In Computer And Communication Engineering, Vol. 5, Issue 12, December 2016.

[3] Pushpendra Kumar, Saurabh Verma, Pradeep Kumar, Sandeep, "Automatic Fire Fighting Robot," International Journal Of Creative Research Thoughts (Ijcrt),2018, Volume 6, Issue 2, April 2018.

[4] Lokesh Venkata Ramana Talabhaktula,Veerraju Daliparthi, Tulasi Ravi Kumar, Dulam Chandra Naga Rakesh, "A Novel Fire Fighting Robot With Arduino," International Journal Of Food And Nutritional Sciences (Ijfans), Vol.10, Iss.1, Jan 2021, E-Issn 2320 –7876.

[5] Anam Sheikh, Gopal Purohit, Vaishnavi.C.Raut, Rehan Rashid Abdul, Prof. C. H. Kidile, "Review Paper On Arduino Based Fire Fighting Robot," International Journal For Research In Applied Science & Engineering Technology (Ijraset), Volume 10 Issue V May 2022, Issn: 2321-9653; Ic Value: 45.98.

[6] Mr. Kondeti Chirunadh, Mr. G. Sai Varaprasad Goud, Miss. G. Tejaswini, Mr. B. Srinivasa Rao, "Arduino Based Fire Fighting Robot," International Research Journal Of Modernization In Engineering Technology And Science (Irjets), Volume:05/Issue:06/June-2023, E-Issn: 2582-5208.

[7] J Jalani, D Misman, A S Sadun And L C Hong, "Automatic Fire Fighting Robot With Notification," Iop Conference Series: Materials Science And Engineering, Volume 637, The 3rd International Conference On Robotics And Mechatronics (Icrom 2023) 9–11 August 2023, Sabah, Malaysia.