

Development of an Artificial Intelligent Firefighting Robot and Experiment Investigation on Fire Scene Patrol

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Abstract: Nowadays, due to human irresponsibility, unpredictable climate fluctuations, and household and industrial settings, fire incidents happen regularly. This study describes a firefighting robot that uses artificial intelligence to identify fire incidents and have capability to put out a fire remotely, minimising the risk to fire fighters. The firefighting robot moves according to a combination of user supervision and sensor-based inputs. Software includes integrated tracking, flame detection, obstacle avoidance, and fire extinguishing. The direction and amount of water sprayed can be adjusted by the servo motor that is attached to the firefighting hose. In the final phase, a simulated fire trial environment was used to assess the firefighting robot's performance. During an autonomous inspection of the fire affected area, the firefighting robot has the ability to identify flame in real time, initiate the automatic fire extinguishing by the fire extinguishing system, and manage the fire during its initial stages.

1 Introduction

As acceleration of industrialisation, more and more people are residing and working in crowded interior structures [1]. Fire damage continues to be expensive from global viewpoint. Statistics show that the total losses brought on by fires, both direct and indirect, make up around one percentage of the world's gross domestic product [2]. These mishaps harm the environment, pollute it, and put people in danger. Many people die as a result of fire accidents. India's industrial development has emerged as a crucial factor in achieving success and keeping up with developed nations. But lately, unintentional events like fire mayhem have posed major challenges to the development of industries. The most discussed subjects in the fields of science and technology are prevention and intervention in such situations [5]. Robots are used for consumer applications and in a variety of industries. One of the autonomous mobile robots with a wide range of potential uses is the firefighting robot. They can be used in confined spaces, hazardous locations for people, and difficult to reach places. Fans are used by the majority of current firefighting robot models to put out the flames [3-5]. In certain applications using firefighting robots, this firefighting tactic is effective. Still, it is ineffective in real-world situations, then in certain instances, it might even spread the fire. Given the aforementioned circumstances, a new avenue for advancement in the discipline of fire prevention has emerged with manufacture of firefighting robots that are equipped with autonomous inspection and automatic extinguishing

capabilities. Firefighters can be assisted or completely replaced by a firefighting robot, which will increase their effectiveness and capacity for fighting fires and performing rescues. Approximately 60% of fire incidents take place indoors, inhalation of smoke, and being trapped in an enclosed fire are the main causes of firefighter fatalities and injuries, according to multiple reports [6–8]. Particularly, firefighters experience emotional fear and are unable to do even their regular tasks due to severely poor sight caused by dense smoke [9, 10]. In dense smoke, visibility is usually less than one metre. Numerous platforms for robotic and visual aids have been created and researched to help firemen carry out their duties in these circumstances [11–14]. The majority of these research have used infrared and visual darkness vision cameras as visualization sensors in their investigations of firefighter visual aids. These sensors are not appropriate for the elevated temperatures of heavy smoke because of their short wavelength. Consequently, a temperature sensor was employed in those investigations to make up for these flaws. An interior air area experiences a large temperature gradient due to the dense smoke. A sensor with an extended wavelength is beneficial for detecting the surroundings under these circumstances. Because of their longer wavelengths, thermal infrared cameras and ultrasonic sensors are therefore better suited for usage in densely smoky settings than optical and infrared scotopic vision cameras [15]. Su et al. [16] used the Adaptive Fusion Algorithm (AFA) to create an autonomous fire detection system. In order to gather data, a multi-sensor fire detection system (MSFDS) was employed, and a generic interface for a supervised computer was created as part of the project. A team of aerial and ground robots was developed by

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Viguria et al. [17] and used for fire detection. They utilized an innovative market-based algorithm to organize between aerial and ground based vehicles. Their mathematical models established that as the quantity of facilities enhanced, so will the essential for energy and communication. So as to identify fires early, Khoon et al. [18] reported the creation of autonomous firefighting equipment that can patrol a hazardous environment using a directing track. They employed an LDR sensor, a flame sensor, and motor circuits to achieve the simplest extinguishing conceivable. The robot LUF60 with a water mist nozzle and a blower was studied by Kim et al. [19]. In order to accomplish the purpose of fighting fires, the blower enhances the flow of water and sprigs it, lowering atmosphere temperature throughout an extensive range. The water hose is attached to a robot's rear end, enabling it to continuously sprig water mist. Based on multi-sensor fusion technology, Zhang et al. [20] created an intelligent firefighting robot that can perform automatic firefighting tasks and autonomous inspection. To find a fire source, the robot works in tandem with a binocular vision camera and an infrared light thermal imager. The following factors show that these robots are presently inappropriate for usage in interior surroundings: These firefighting robots are large and cumbersome to move inside; (ii) at the moment, utilize water as major extinguishing medium in these robots and need an outside water pipe; still, the interior area is small, has numerous turns, and the motion of the robots is constrained by the water hose. Based on the aforementioned problem, the development of an indoor firefighting robot is the subject of this research. The robot can automatically put out fires in addition to doing autonomous inspections. The firefighting robot appears flexible and has unrestricted movement inside. In addition, the robot has the ability to apply various fire extinguishing agents based on the kind of burning objects it detects.

2 Materials and Methods

Effective operation of a firefighting robot necessitates precise control over its mechanical construction. The control of a firefighting robot consists of three separate phases: perception, processing, and action. Sensors provide data regarding the surroundings or the internal state of the firefighting robot, such as the location of its joints or the characteristics of its end effector. Subsequently, this data is analysed to determine the suitable commands for the actuators, which in turn control the mechanical components. The approach is segmented into three components. The initial section focuses on the mechanical schematics, followed by a description of the hardware, and concluding with the programming design. The components were constructed and subsequent trials were conducted to ascertain the ideal distance at which firefighting robot could quench the fire.

2.1 Design of Mechanical Structure

The primary configuration of the firefighting robot consists of one set of wheels at the back side and other set of wheels at the front in order to achieve anticipated movement and speed. The wheels possess capacity to stabilise firefighting robot and execute a full 360-degree revolution. The robot's body is constructed using acrylic plate to safeguard the electronic circuitry. The configuration of the fire extinguishing robot is depicted in Figure 1.

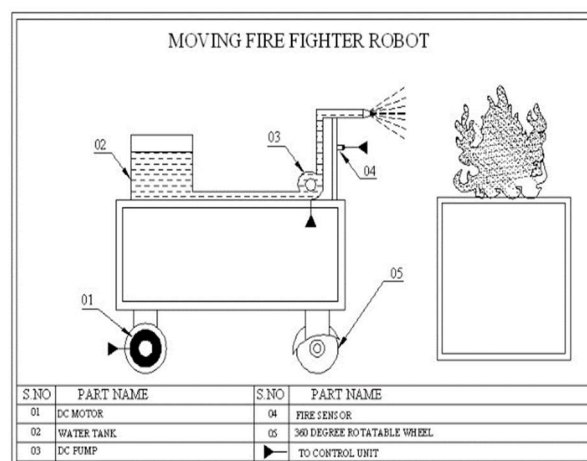


Fig. 1. Schematic of robot

The acrylic sheet exhibits a high resistance to temperatures reaching 200°C. The acrylic chassis is designed with strategically placed holes to facilitate the mounting of a mechanical components and wide range of sensors. The ultrasonic sensor was positioned at the front side of the robot to prevent collisions with obstructions, while the flame sensor was attached to identify the presence of fire. Furthermore, a little camera has been mounted on the front end of the robot to observe and assess the path and state of the surroundings. This camera is linked to smartphone.

3 Hardware Implementation

The electronic components performance a vital role in the advancement of firefighting robots. The components of this system consist of a microcontroller, various types of sensors, a transmitter, a DC motor with a wheel, a water pump, and remote control. Figure 2 depicts the illustrating the procedure of the firefighting robot. The system incorporates an ultrasonic sensor and flame sensor as input components. The Arduino serves as a microcontroller that is interconnected with many additional components. The Motor Driver (L298N) is utilised to initiate motion of the servo motor, whereas the Remote Control provides the system's output. The water flow and fire extinguisher were activated by the operator after being controlled. Alternatively, the operator can observe the robot's actions through a camera that is connected to a smartphone.

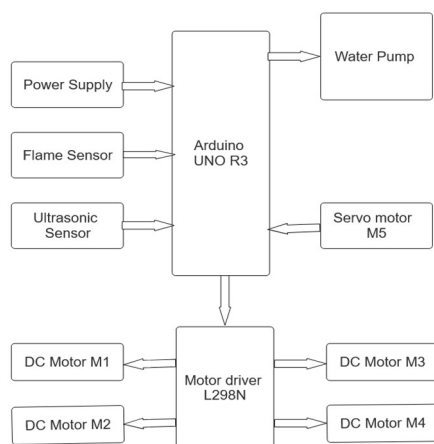


Fig. 2. Working Principle of firefighting robot

3.1 Flame Sensor

Fire sensors performance a critical role in investigations for majority of firefighting robots; they are always utilised as the eyes of the robot to find fire sources [1]. The sensor can be utilized to detect the wavelength of light of fire, which ranges from 760 to 1100 nm. The detecting approach is about 60 degrees, and the range of the distance is 20 to 100 cm. Analogue Output (AO) and Digital Output (DO) are the two signal pins on the flame sensor. While AO pins identify the precise wavelength of various light sources, DO pins provide two types of information: whether or not there is a flame present.

3.2 Ultrasonic Sensor

Barricade and obstacle evasion is one of the furthestmost significant parts of creating an autonomous robot. It should also have sufficient sensing range to enable robots to acknowledge and move accordingly. These sensors are only satisfied the all of these criteria. In this investigation, the HC-SR04 sensor is utilized to measure the area between 2 cm and 400 cm at a 15 degree angle. This sensor transfer wavelength into space and picks up waves that are reflected back from the item. It has four output pins: ground (GND), digital output (DO), analogue output (AO), and reference voltage (VCC), which operates at about 5 volts.

3.3 Mobility of Robot

The robot is moved by use of a caster ball and two nylon wheels. This vehicle is primarily rear-wheel drive. Two different shafts support two motors that are positioned alongside the nylon wheel. The wheels have a diameter of 3 inches and a thickness of 0.8 inches. A motor driver (L298) that reacts to an Arduino signal controls the movement of the motors. Both torque and speed are high in the motors. Even when empty, these locally produced motors do not operate at the same pace. Additionally, the robot's weight does not appear to be distributed evenly. Thus, an algorithm is developed and coded to independently control each of the two motors. Then, in order to match the speeds of both motors and enable them to travel straight in a designated direction, an extreme

calibration is performed. Caster balls are used because they are inexpensive and simple to use. The back wheels of the robots primarily govern their movement. A caster ball is utilised to provide flexible motion and front support.

3.4 Water Spreading Mechanism

The water container may hold a minimum of one litre of water. The screw and glue mechanism is used to secure the pump to the container. Here, the glue is waterproof. The pump is installed in an extended aluminium pipe. Since water have to be heaved while maintaining a secure area from fire, the pipe is around two feet long. The water is spread at the front of the pipe using a locally manufactured water spreader. When a spreader is used, the water flow from the pump is significantly reduced while still spreading the water efficiently for extinguishing purposes. Therefore, extending the pipe maintains a safe distance from the source.

3.5 Transmitter and Remote Control

Four different control modes will be available in the wireless remote-control transmitter and receiver used in this investigation. This receiver/remote's model number is S4C-AC110. This remote have four buttons for control the robot. The voltage range of the remote control is AC 100–120 V, but the voltage range of the relay is either DC 0–28 V or AC 110–240 V. The remote control is 100 metres, away. The power source of the transmitter is 12 V. The frequency limit of transmission is 315 MHz / 433 MHz. Robots can be supervised remotely with the assistance of a transmitter and controller, permitting the operator to persist in a protected area while the robot navigates hazardous fire region.

4 Control Programming

In the firefighting robot, Arduino Uno is its only logic control unit. Arduino Uno provides an Integrated Development Environment (IDE) for the C and C++ programming languages. It contains a 16 MHz quartz crystal, 14 digital input/output pins, 6 analogue inputs, a USB port, an ICSP header, a power jack, and a reset button. Using jumper wires and a breadboard, the output and input pins are connected to the motor, pump, and sensors in various ways. By doing this, it gives control over every part of the robot, enabling it to do its duties in accordance with the Arduino Uno's software. The LiPo battery is the only power source control unit. The motor, pump, and entire circuit are powered by a lithium polymer battery. It is 12V, 2200 mAH battery. It is a lithium-ion rechargeable battery in the form of a pouch. Although these batteries are less stiff, they are also lighter. The 7808 IC steps down the battery voltage to 8V so that the Arduino may be powered. Because this voltage is optimal for Arduino's operation. The robot's chosen motors and pump work best when powered by 12V. So, it was wise to get a 12V LiPo battery. For the purposes of detection and extinguishment, a multisensor

fire detection system (MSFDS) is employed. This technology allows for the simultaneous use of multiple sensors as well as the cooperation of the sensors. The Arduino Uno is connected to the LM35 and the Arduino Flame Sensor, two extremely sensitive sensors. The Arduino flame sensor is extremely responsive to light between 760 and 1100 nm in the infrared spectrum. Short-range fire detection is accomplished by using these kinds of sensors. There are four pins on it. Positive voltage input (VCC): 5 volts for analogue, 3.3 volts for digital, analogue output (A0), digital output (D0), and ground (GND). It produces an analogue output after receiving input from the environmental data. It recognises a flame and raises the analogue output if there is a noticeable shift in the infrared wavelength. After that, the robot's programming causes it to begin moving in the direction of the flame. With an output voltage that is straightly proportionate to the temperature in centigrade, the LM35 is a rigor integral circuit temperature sensor. The outcome of this sensor is a proportionate temperature value. The LM35 detects a notable temperature rise close to the flame source when the robot travels in its direction and modifies the output. In the event that this output varies drastically, the robot is designed to stop. Two safety precautions have been implemented because LM35 needs to be quite close to the source in order to detect heat. One temperature sensor is linked to the control unit through a lengthy wire that is housed confidential a pipe that is roughly 10 inches long. As a result, the sensor stays well away from the main body. Two, it senses an increase in temperature and immediately stops the motor to return to a safe and convenient throwing distance.

5 Working Principle and Test Procedure

The robot spins on its own axis when it first starts up. Arduino will use the motor driver to control the motor. The body will revolve as a result of one motor remaining off and the other moving. The robot rotates in this manner to check for fire in various room corners. The Arduino flame sensor will ultimately track down fire. The robot will then gradually advance towards the fire. In this case, an algorithm is required to enable the robot to approach the fire slowly. For the robot must come to an endpoint and it must not interfere with the fire in any way. Heat is sensed using the LM35 sensor. When it detects a noticeably higher temperature, it halts and retreats a small distance to allow for extinguishing. To put out the fire, a centrifugal pump then squirts water at it. Water can be dispersed thanks to a special mechanism. The purpose of trial is to determine the sensitivity of the LM35 and flame sensors at various hours of the day and at various separations from the fire source. A candle is positioned in relation to the Arduino flame sensor at various distances for various tests. Three feet away from the fire source is the best stable reading that can be found at the analogue output of the serial monitor. Readings are taken from that distance at different times of the day,

every half an hour, with or without the fire source. The robot moves towards the fire when it is recognized by the flame sensor. The readings are recorded at intervals of three inches. The temperature rises and the LM35's output changes as the robot approaches the source; these variations are also recorded. The experiment took place on March 22, 2024. The day's high was 33 degrees Celsius on average.

6 Results and Discussions

Robots designed to battle fires have been created that can locate and put out fires. Robots are able to locate objects utilising ultrasonic and flame sensors. While the ultrasonic sensor is used to identify objects nearby the robot, the flame sensor locates the source of the fire. The Arduino Uno, which was connected to both sensors, was in charge of the motion of DC motor. At 40 centimetres distance from the fire, the DC motor will shut off when the flame sensor recognizes a fire. The robot operator will utilize a controller to put out the fire from a good way. Additionally, the robot operator might watch out on the robotic by connecting a camera to a Smartphone.

6.1 Time Taken to Extinguish Fire

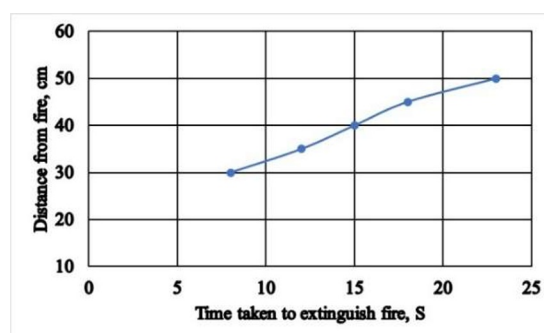


Fig. 3. Extinguish of fire depends on distance with time

Robots successfully locate the source of the fire on their own and put it out with operator direction. Using a camera attached to their smartphone, the operator can keep an eye on the fire's location. Figure 3 illustrates how the distance between Robotic and the fire throughout the fire suppressing operation affects what amount of time it requires to put out a fire. It is evident from the experiment results that the more it takes to put out a fire, the more prominent distance among Robotic and the fire.

6.2 Time Taken to Find the Distance

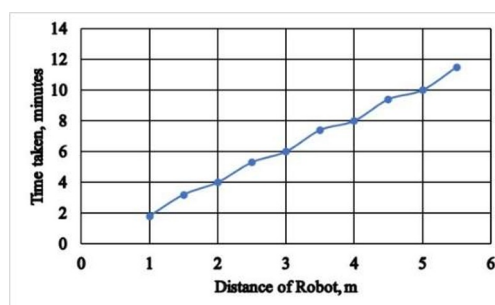


Fig. 4. Time taken depends on distance of robot

Fig. 4 shows that the robot's distance route determines how long it takes to reach the fire spot. According to the experimental findings, the robot's route length and the amount of time it takes to reach the fire location are directly correlated.

6.3 Responsiveness of Flame Sensor

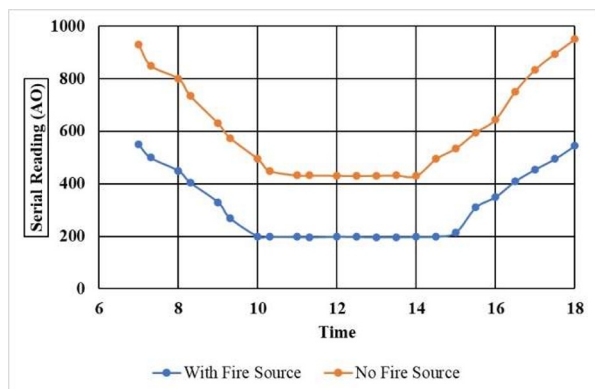


Fig. 5. Outcome of responsiveness of flame sensor at day

Fig. 5 shows the results of testing the Arduino Flame Sensor's sensitivity both during the day and at night, when there is no fire, and from a distance of three feet from the fire source. However, the reading continues to decline with time. This is a result of the sunlight's infrared radiation. The sun reaches its peak strength at 12 or 13 o'clock, increasing the amount of infrared light available for the flame sensor to detect. Thus, whether there is a fire source present or not, this time of day yields the lowest output reading. However, the sun's intensity begins to diminish after 15 o'clock, which causes the output reading to rise. When the Sun sets at the end of the day, it reaches its highest value. Additionally, it was noted that nearly parallel patterns were discovered and that the reading profiles of serial essentially preserved a consistent equilibrium throughout the day.

6.4 Variation in the Output Signal of Flame Sensor Once the Robot Approaches Fire

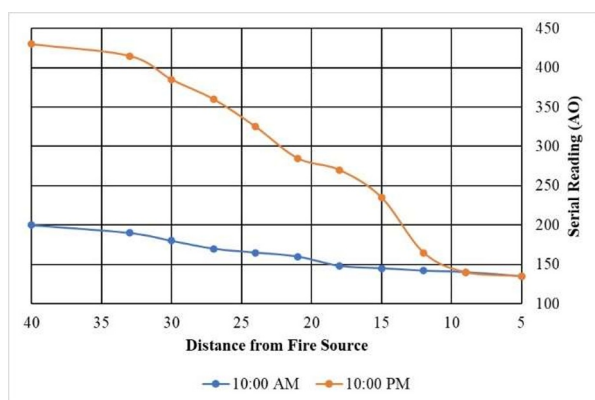


Fig. 6. Variation in the output signal of flame sensor once the robot approaches fire

At 10 PM, the reading declines more sharply than it does at 10 AM. because the Sun's infrared rays around 10 AM cause the sensor's analogue reading to be disturbed. However, it's also discovered that the readings

during the day and night are nearly identical when they're close to the safe distance from the fire, because the effect of fire starts to dominate. Additionally, it is noted that in both circumstances, the curve steepens equally at close proximity to the fire source. Since infrared rays are produced in greater quantities when a source's intensity increases. As a result, the output reading at 10 PM experiences a sharp attenuation, but at 10 AM, it experiences a moderate attenuation.

7 Conclusions

In this investigation, a firefighting robot that can automatically put out fires and conduct autonomous inspections was developed. Two main pieces of hardware make up the independent inspection system: a sensor unit and a motion unit. Over its independent inspection and computerized fire smothering trial, the robot demonstrated real-time flame detection and extinguishing capabilities. It detects flames more accurately in dimly lit areas. It is designed to be a robot preventer due to its ability to quickly detect fire and put it out before it spreads. This robot has capability to prevent hit any hindrance because of its establishment of an ultrasonic sensor. The robot operator can to put out a fire utilizing controller from better distance. Operators can likewise screen the ecological circumstances throughout the procedure of firefighting by utilizing camera. From trial outcomes, the robot can identify smokes and fire precisely in a brief time frame. At night, the outcome values have moderately greater value without fire source and smallest value is acquired without occurrence of fire. This gives a decent scope of identification. After recognition of fire, the robot begins to progress towards the source. With the modification of temperature, the result of LM35 is altered. This multimodal robot could be the answer to every fire threat. The robot reduces the effort of firefighters and lowers the number of large fires by carrying out two tasks: autonomous inspection and automatic fire extinguishing. This robot's design, given sufficient budget and scope, is also capable of fighting against huge fires. Its higher reserve capacity and enhanced sensing unit allow for even quicker fire detection in all situations.

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